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THE VALUE IN HYBRID COMBINATIONS OF INBRED LINES OF CORN SELECTED FROM SINGLE CROSSES BY THE PEDIGREE METHOD OF BREEDING[1]

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THE utilization of inbred lines of corn in hybrid combinations has been studied extensively by many investigators. Most of the inbred lines used in these studies, however, have been obtained by self pollination and selection from commercial varieties. Recently, Hayes and Johnson (2)[3] and Wu (6) at the Minnesota Station have presented the results of breeding improved inbred lines by what was designated as the pedigree method of breeding. As the method was described in considerable detail in these earlier publications, it seems unnecessary to summarize here in great detail. Inbreds were selected from single crosses between inbreds obtained from commercial varieties. Each of the nine crosses from which inbreds were selected was made for the purpose of combining the desirable characters of the parental inbreds and after crossing selection in self-pollinated lines was practiced from F_2 to F_6 before the new inbreds were considered sufficiently homozygous to be ready for use in hybrids. During the segregating generations selection was made for ability to withstand lodging and for resistance to smut as well as for general plant vigor. Inbreds obtained by this method of breeding are much superior in ability to withstand lodging to those obtained by selection from Minnesota open-pollinated varieties. Before testing the new inbreds in single and double crosses they were tested in inbred-variety crosses with Minn. No. 13. Previous investigations (3, 4, 5) of inbred-variety crosses have led to the general acceptance of this method as a means of discarding lines of low combining ability.

The present study was made to determine the relation between the performance of inbreds in inbred-variety crosses and in single crosses. Since crosses were made also between lines of diverse as well as some-

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[3]Figures in parenthesis refer to "Literature Cited," p. 485.

what similar origins, additional data are presented to show the value of genetic diversity in origin of inbred lines in relation to their yields in single cross combinations.

MATERIALS AND METHODS

The inbred-variety crosses were studied in replicated plot trials grown in three localities in 1936 and 1937 as has been described in considerable detail by Wu (6). The yields of these inbred-variety crosses were corrected to the regression of yield on moisture, the correlation coefficient for the relation between yield on a 14% moisture basis and moisture percentage of ears at husking being $+.315 \pm .086$. The corrected yields were expressed as percentages of the average yield of Minn. No. 13 and Minhybrids 401 and 402 and were placed in four groups for yielding ability, group 1, 80 to 89; group 2, 90 to 99; group 3, 100 to 109; and group 4, 110 or more.

Single crosses made between selected inbred lines were tested in 1939 in several representative areas of the state to which they were adapted. The northern group of early maturing single crosses were grown in three replications at each of four locations, *viz.*, University Farm, St. Paul; North Ottertail County; Todd County; and Clay County. This gave an opportunity to compare single crosses from unrelated inbreds with single crosses between inbreds with 1% in common as explained by Hayes and Johnson (2). In these trials there were 19 single crosses between unrelated inbreds classified on the basis of top cross performance in groups 3×3, 3×4, and 4×4 and 14 single crosses between related inbreds with one parent in common. These crosses were tested in three groups of randomized block trials with not more than 24 varieties per block and including Minhybrids 401 and 402, previously known to be outstanding in yield performance (1). In these studies Minhybrid 401 gave an average yield on a 14% moisture basis of 48.2 bushels with a moisture content at husking of 25.9%, while Minhybrid 402 yielded 43.7 bushels with a moisture content at husking of 21.6%. The difference in yield was 4.5 bushels and in moisture content 4.3%. As some of the hybrids were earlier than Minhybrid 402, a calculated standard yield and moisture percentage were used to compare with the early hybrids by assuming a direct reduction of a bushel in yield below Minhybrid 402 for each reduction of 1% in moisture content at husking.

The yields of single crosses were compared with Minhybrids 401 or 402 or the calculated standard and placed in frequency distributions based on from minus 6 to plus 5 times the standard error of a difference. Thus in group 1 the calculated standard error of a mean obtained from the analyses of variance was 1.2 bushels for the average of the four locations. The standard error of a difference was 1.9 bushels and the class centers for plus and minus differences were 1.9, 3.8, 5.7, 7.6, and 9.7 bushels for the standard error of a difference multiplied by 1 to 5, respectively. The yield of each single cross was compared with a standard and entered in the frequency table according to the extent of its difference from the standard.

In the north central group of single crosses grown at three locations, University Farm, St. Paul; Meeker County; and the Morris branch station, there were 12 single crosses between groups 1×1 or 1×2 as classified by the yielding ability of the inbred-variety crosses, 14 single crosses of groups 1×3 or 1×4, and 28 single crosses from groups 2×3 or 2×4. In these trials Minhybrid 402 yielded an average of 61.9 bushels with a moisture percentage at husking of 17.5%. Minhybrid 401

yielded 66.1 bushels with a moisture content at husking of 20.8% and Minhybrid 301 yielded 77.0 bushels with a moisture content of 23.1%. There were only a few single crosses as late as Minhybrid 301 and these were compared with 301. Intermediate standards for moisture content between that of Minhybrid 301 and 401 or 401 and 402 were calculated by averaging the yields and moisture content of the appropriate hybrids. As there were a few hybrids earlier than 402 calculated standards were obtained as explained for the northern group. The yield of each single cross was compared with a standard of similar moisture content at husking.

Medium maturing single crosses were tested in central Minnesota in four locations, *viz.*, at University Farm, St. Paul; the Morris branch station; Stearns County; and South Ottertail County. These included 10 single crosses from unrelated parentage from groups 2×3 or 2×4, 64 single crosses from unrelated parentage from groups 3×3, 3×4, or 4×4, and 24 single crosses from related inbreds with one parent in common from groups 3×3, 3×4, or 4×4. In these studies the crosses were compared directly with a standard hybrid of similar moisture content or with the average of 401 and 301 or 401 and 402. Average yields and moisture percentage of Minhybrids 402, 401, and 301 were 55.5 bushels with a moisture percentage of 19.5 for 402, 60.7 bushels and 24.7% moisture for 401 and 64.3 bushels with 27.6% moisture for 301.

EXPERIMENTAL RESULTS

As previously explained, the average yield of each single cross was compared with the yield of an appropriate standard for similar moisture content at husking, based on the moisture content and yield of the standard Minhybrids 401, 402, or 301. This may be illustrated in detail by three crosses grown in central Minnesota. The yields and moisture content of these crosses are as follows:.

Percentage yield of inbred parents in inbred-variety crosses	Yield of single crosses, bu.	Moisture content of crosses, %
110 and 120	60.4	26.6
110 and 112	63.7	23.9
112 and 122	59.8	20.2

Yields in bushels per acre and moisture percentage at husking of the standard hybrids in this trial were as follows:

Standard hybrid	Yield, bu.	Moisture, %
Minhybrid 402	53.5	19.4
Minhybrid 401	60.4	23.9
Minhybrid 301	62.9	27.6
Average, 401 and 402	57.0	21.7
Average, 401 and 301	61.7	26.0

The computed standard error of a difference, by an analysis of variance, for these trials was 2.36 bushels. Each of the crosses was then compared with the appropriate standard by obtaining the difference in yield between the standard and the cross concerned, and entered in the correct frequency distribution with class centers at 0, + or

-1, $+$ or -2, etc. The 0 class contained all deviations lying from 0 to plus or minus 1.1, class 1 from 1.2 to 3.5, class 2 from 3.6 to 5.9, etc.

The cross that yielded 60.4 bushels with moisture content of 26.6% was compared with the average of 401 and 301 giving a lower yield than the standard of 1.3 bushels which placed it in the frequency class for -1 times the standard error of a difference. The second cross with a yield of 63.7 bushels and a moisture content of 23.9% was compared with Minhybrid 401 giving an increase in yield of $+3.3$ bushels which placed it in the frequency class for $+1$, while the third cross was compared with Minhybrid 402 giving an increase in yield of 6.3 bushels placing it in the frequency class for $+3$.

The summary of results for the single crosses grown in each of the three locations and classified for yield as shown above is given in Table 1.

Comparisons of these results will not be made in great detail. In the North Central region there were 12 single crosses between inbreds belonging to inbred-variety groups 1 or 2. The mean deviation of this group was -0.50 ± 0.66. The 28 single crosses of group 2 with groups 3 or 4 gave an average mean deviation of $+1.61\pm0.68$. The difference between these two types of crosses was 2.11 ± 0.95. In the central location single crosses of unrelated parentage gave an opportunity to compare 10 crosses of groups 2×3 or 2×4 with 64 crosses of groups 3×3, 3×4, or 4×4. The mean difference was 0.74 ± 0.46. These results give some evidence that the yielding ability of inbred lines in inbred-variety crosses is not closely related to average combining ability in single crosses when inbred parents are widely dissimilar in origin. As all single crosses were compared with appropriate standard double crosses it seemed desirable to combine the comparisons for the three locations to obtain a larger number of crosses within each group.

The data from the three locations were combined in a single frequency table giving an opportunity to compare the yielding ability of the single crosses with an appropriate standard double cross of similar maturity. The crosses were classified also into groups on the basis of the combining ability of the parents in inbred-variety crosses, as has been explained. Groups 1 and 2 with inbred-variety cross yields from 80 to 99 were considered as low combiners, while groups 3 and 4, yielding from 100 to 122, were considered as high combiners. The data from crosses of unrelated inbreds are given in Table 2.

The 12 single crosses from inbred parents both classified as low combiners gave a mean deviation of $-.50\pm0.66$ and the 52 single crosses between inbred lines in which one parent was classified as low and the other as a high combiner gave a mean deviation of $+1.06\pm0.42$. The difference between these two groups of crosses of 1.56 ± 0.78 may be considered to be significant. The 52 single crosses between groups, designated low$\times$high, gave the same mean, 1.06 ± 0.42, as the 83 crosses from yielding groups of high$\times$high with a mean of 1.14 ± 0.24.

From the data given in Table 2 summarizing the distribution of yields from 147 single crosses between inbred lines of unrelated origin,

TABLE 1.—*Frequency distribution of single cross yields when compared with recommended Minnesota hybrids of similar maturity in relation to the inbred-variety cross combining ability of their inbred parents classified into groups 1, 2, 3 and 4 based on percentage yield in inbred-variety crosses of 80–90, 90–99, 100–109, and 110 or above, respectively.*

Group of inbred parents	Location of trials	Class centers of plus and minus 1 to 8 times the S.E. of a difference																	Total	Mean class
		−8	−7	−6	−5	−4	−3	−2	−1	0	1	2	3	4	5	6	7	8		
Unrelated 1×1 or 1×2	North Central	—	—	1	—	—	1	1	1	4	2	2	—	—	—	—	—	—	12	−0.50±0.66
Unrelated 1×3 or 1×4	North Central	—	—	—	1	—	—	—	3	1	5	2	—	1	—	1	—	—	14	+0.79±0.68
Unrelated 2×3 or 2×4	North Central	—	1	1	1	—	—	2	2	2	1	5	3	5	3	1	—	1	28	+1.61±0.68
Unrelated 3×3, 3×4 or 4×4	Northern	—	—	—	—	—	—	—	1	1	1	2	8	4	2	—	—	—	19	+2.84±0.35
Related 3×3, 3×4 or 4×4	Northern	—	—	1	—	2	3	2	3	—	2	—	1	—	—	—	—	—	14	−1.79±0.63
Unrelated 2×3 or 2×4	Central	—	—	—	—	—	—	1	3	3	2	1	—	—	—	—	—	—	10	−0.10±0.38
Unrelated 3×3, 3×4 or 4×4	Central	—	—	—	1	1	4	5	6	7	18	12	6	2	2	—	—	—	64	+0.64±0.26
Related 3×3, 3×4 or 4×4	Central	—	—	—	2	2	—	8	4	4	1	2	1	—	—	—	—	—	24	−1.25±0.42

TABLE 2.—*Summary of frequency distribution of single cross yields at all locations when compared with recommended Minnesota double crosses of similar maturity in relation to the inbred-variety combining ability of their inbred parents.*

Type of cross	Class centers of plus and minus 1 to 8 times the standard error of a difference																	Total	Mean class
	−8	−7	−6	−5	−4	−3	−2	−1	0	1	2	3	4	5	6	7	8		
Low×low	—	—	1	—	—	1	1	1	4	2	2	—	—	—	—	—	—	12	−0.50±0.66
Low×high	—	1	1	2	—	—	3	8	6	8	8	3	6	3	2	—	1	52	+1.06±0.42
High×high	—	—	—	1	1	4	5	7	8	19	14	14	6	4	—	—	—	83	+1.10±0.24

a total of 63, or 43%, yielded significantly higher than a recommended standard double cross of comparable maturity. This unusually high percentage of successful combinations would suggest that the pedigree method of breeding inbred lines of corn not only has been of distinct value in the production of inbred lines with desirable agronomic characters but likewise offers an opportunity to impart to those inbred lines unusually high combining ability as measured by single cross yields. This property is undoubtedly associated with the large degree of genetic diversity between inbred lines selected from divergent sources and would be expected to occur on the basis of the Mendelian explanation of heterosis.

Additional information on the relation between the genetic diversity of inbred lines and their yields in hybrids in given in Table 3. Since the inbred-variety cross performance of the two groups of lines used in these crosses was similar (groups 3 and 4), the principal difference between the two groups of crosses is the extent of similarity in their parentage. The "related" inbred lines were obtained by selection in the segregating progeny from crosses between inbred lines and were combined in such a manner that one of the parents of the original single crosses was in common in each of the two original crosses from which the inbred lines were selected.

TABLE 3.—*Frequency distribution of single cross yields when compared with recommended Minnesota hybrids of similar maturity in relation to the extent of genetic relationship of their inbred parents.*

Relationship of inbreds	Class centers of plus and minus 1 to 7 times the standard error of a difference														Total	Mean class
	−6	−5	−4	−3	−2	−1	0	1	2	3	4	5	6	7		
Unrelated........	—	1	1	4	5	7	8	19	14	14	6	4	—	—	83	$+1.14\pm0.24$
Related..........	1	2	4	3	10	7	4	3	2	2	—	—	—	—	38	-1.45 ± 0.35

There were 83 single crosses between unrelated inbreds and 38 between related inbreds, the mean deviations of the yield of single crosses from the two types of crosses being $+1.14\pm0.24$ and -1.45 ± 0.35, respectively, or a highly significant difference.

SUMMARY OF RESULTS

1. In a study of single crosses between inbred lines bred by the pedigree method from single crosses, a comparison was made between their inbred-variety cross and single cross performance.

2. The evidence obtained from 12 single crosses between relatively low combining inbreds indicates that single crosses between low combiners may be expected to yield somewhat lower, on the average, than single crosses from relatively high combining inbreds when the single crosses are made between inbreds of diverse genetic origin. Single crosses between low combining inbreds with high combiners yielded as well, however, as single crosses between high combiners. The proportion of high yielding single crosses from low×high combiners was as good in this study as from high×high combiners.

3. Additional data from crosses between related inbred lines indicate that diversity in genetic origin is an important factor in obtaining the maximum expression of hybrid vigor.

4. From a comparison of 147 single crosses between inbreds of unrelated origin with recommended double crosses, 63, or 43%, yielded significantly higher than the double crosses used as a standard. These results indicate the desirability of selecting inbreds for use in double crosses from crosses between inbred lines that have superior characters, thus giving an opportunity to combine in a single inbred the desirable characters of its two parents.

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	−6	−5	−4	−3	−2	−1	0	1	2	3	4	5	6	7		
Unrelated........	—	1	1	4	5	7	8	19	14	14	6	4	—	—	83	+1.14±0.24
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THE TESTING OF BUFFALO GRASS "SEED", *BUCHLOE DACTYLOIDES* ENGELM[1]

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BUFFALO grass is one of the chief components of the grassland vegetation of the Great Plains area. This plant, because of its low-growing, stoloniferous habit, forming dense and extensive ground cover, is of great value for grazing and in soil conservation. Under favorable conditions a single plant produces numerous radial stolons which root at the many nodes. It is dioecious (4)[3] and occasionally monoecious (1), but at times bears a few perfect flowers on the staminate spike (3, 6). The staminate and pistillate inflorescences are borne on separate plants or separate branches which propagate their own kind. The fruit or "bur" consists of one or two to four spikelets whose glumes have become hardened and fused about the loose grains.

According to Savage (5), the seeds usually germinate poorly, a statement needing confirmation. A poor stand of buffalo grass from seed, according to the evidence herein presented, may be due to (a) early harvesting of the seed, (b) low purity, and (c) low caryopsis count.

Early harvest.—When burs were immature, or mature but not weathered, germination was found to be very low. When, however, burs were weathered, thereby indicating a long period on the ground, and harvested late in the fall, during the winter, or early spring, germination within 10.0% of the caryopsis count was usually obtained. (See Table 1.)

Low purity.—Inasmuch as the burs of buffalo grass must be harvested from on or close to the ground, large amounts of debris apparently of similar bulk and specific gravity, form a major part of the bulk seed under the present methods of harvesting. The average purity of seed harvested in 1937 and winter of 1938 was 34.02%, that of the 1938 harvest 29.63%, and that of 1939 (one sample) 41.51%.

Low caryopsis count.—As the purity figure represents the percentage of burs and cannot include a separation of the number containing caryopses and those which are empty, or completely necrotic, the caryopsis count reduces the amount of pure live seed still further. The germination can be predicted within 10.0% of caryopsis count, provided that the seed has been harvested after it has received some degree of weathering. The average count of the 1937 (and winter of 1938) seed was 72.16%, and that of the 1938 harvest 57.69%.

Thus it is the low purity (the result of harvesting difficulties) and caryopsis count which, according to the evidence herein presented,

[1]Contribution of the San Antonio, Texas, Seed Laboratory, No. 1. The earlier tests were carried on in the Division of Seed Investigations, Bureau of Plant Industry, Washington, D. C., during 1935–36. The later tests were made at the Soil Conservation Service Seed Laboratory, San Antonio, Texas. The cooperation and suggestions of the personnel of both laboratories, of the SCS Nursery Division, and of Mr. H. B. Parks, Chief, Texas State Division of Apiculture, are gratefully acknowledged. Received for publication February 19, 1940.

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[3]Figures in parenthesis refer to "Literature Cited", p. 494

TABLE 1.—*The percentage of purity, caryopsis count, degree of weathering, and germination of buffalo grass from various localities.*

Lab. No.	Date of harvest	State	Appearance of burs	Percentage purity	Percentage burs with caryopses	Percentage of germination	
						Check*	Highest†
			Harvest of 1935‡				
271117	Mar. 21, '35§	Texas	Weathered	—	—	66.7	—
258113	June 26, '35	Texas	Slightly green	—	80.0	3.5	47.0**
758114	Mar. – '35	Texas	Weathered	—	88.0	46.7	78.0
758304	Aug. '35§	—	—	—	78.0	19.3	61.3**
758409	Sept. '35§	Okla.	Diseased	—	12.0	16.0	—
758307	Aug. '35§	S. Dak.	Barely mature	33.58	80.0	16.5	65.0**
758476	Aug. 26, '35	Kansas	—	92.0	—	58.0	58.0
759304	Nov. 29, '35	Kansas	Weathered	—	—	82.0	82.0
			Harvest of 1937 to February 1938				
S-74	July 24, '37	Texas	Weathered	8.90	78.0	34.0	66.5**
S-197	Aug. 14, '37	Texas	Partly weathered	27.40	76.0	58.0	70.5**
S-198	Aug. 14, '37	Texas	Partly weathered	33.20	76.0	52.0	73.0**
S-199	Sept. 30, '37	Texas	Partly weathered	19.65	54.0	51.5	55.0**
S-205	Sept. 30, '37	Texas	Partly weathered	60.67	85.3	32.0	83.0**
S-229	July 17, '37	Texas	Partly weathered	69.12	76.5	55.2	75.0**
S-249	Jan. 31, '38	Texas	Weathered	22.03	61.0	51.5	58.7**
S-250	Feb. 28, '38	Texas	Weathered	31.22	72.0	61.5	61.5
Averages				34.02	72.4	49.5	67.9
			Harvest of 1938				
S-295	Aug. 16, '38	Texas	Mostly weathered	26.51	56.14	9.5	46.5**
S-297	Aug. 16, '38	Texas	Mostly weathered	21.65	36.97	33.0	39.5**
S-302	Sept. 17, '38	Texas	Partly weathered	30.43	68.2	46.0	55.7**
S-303	Sept. 17, '38	Texas	Mostly weathered	17.25	69.0	39.5	65.8**
S-606	Oct. 29, '38	Texas	Partly weathered	52.32	58.15	47.5	54.5**
Averages				29.63	57.69	35.1	52.4

*Check test germinated at room temperature to 35° C alternation. Room temperature, 17 hours; 35° C, 7 hours.

†Highest germination obtained by any method is indicated to show that germination within 10.0% of the caryopsis count, or within the germinating capacity of the sample, can be obtained although special treatments may be required. There are approximately 52,000 burs per pound.

‡Data incomplete because of small size of samples. In most cases the seed was entirely used for germination tests before the value of other characteristics mentioned above was realized. Samples were tested in the Division of Seed Investigations, Bur. of Plant Industry; submitted by Division of Forage Crops and Diseases or by Soil Conservation Service.

§Date received. **Chilled.

would warrant more attention than germination in determining the establishment of buffalo grass from seed because they are less easily controlled. The actual germination itself can be controlled by harvesting the seed when sufficiently weathered.

DISEASES

In making purity tests, the presence of a few to many grayish weathered and enlarged axillary buds was observed in nearly all samples received. Upon sectioning these were found to contain nematode sacs filled with dormant living nemas. The nematode galls were first observed on living buffalo grass on February 22, 1937, at the San Antonio Nursery. Most of the galls occurred in the deformed nodal buds at the ground line, although a few were observed 4 to 5 inches up from the base of the plants. The buds in which the nematode sacs occurred were apparently killed, since no further development of the buds into normal stolons or fruiting branches occurred. However, other healthy buds from the same nodes produced normal growth. The living galls usually contained a large number of larval and two or more adult nematodes. According to G. Steiner of the U. S. Bureau of Plant Industry, the nematode form is a new *Anguina* species and will be described by him in the near future.

That the disease is widespread, at least in Texas, is evident from the following list of counties from which specimens are now on hand: Bell, Bexar, Coryell, Dallas, and Williamson. The disease was also reported from Oklahoma by Gernert (2).

The economic importance of the parasite has not yet been determined and the diseased patches thus far observed only in the spring have been small.

After many tests of buffalo grass seed in the laboratory, the writer has found no evidence that the germination itself was directly affected by the presence of nematode galls in samples tested, but rather indirectly as staminate and pistillate inflorescences were aborted and the set of seed consequently reduced in a given stand.

Other parasitic organisms found on buffalo grass samples examined to date included the following fungi: *Phyllachora graminis* (P) Fckl.; *Cercospora seminalis* E. & E.; *Helminthosporium inconspicuum* C. & E. *var Buchloe* E. & E.; *Alternaria sp.*; and Witchbroom (organism as yet undetermined).

One sample of burs from Stillwater, Okla., showed a 64.0% infection with *Helminthosporium inconspicuum.*

PURITY DETERMINATION AND CARYOPSIS COUNT

The purity of the buffalo grass seed tested by the laboratory was very variable for the reasons outlined under "low purity." The drop in the average purity of the 1938 lots, as compared with those of 1937, was probably caused by the extreme drought of that year. The lowest purity of the 1937 harvest was 8.9%, the highest 69.12%, and the average 34.02%. The lowest purity of the 1938 harvest was 17.25%, the highest 52.32%, and the average 29.63%.

The drought also affected the set of caryopses, thereby reducing the average percentage of filled burs from 72.16 (1937) to 57.69

(1938). The lowest percentage of filled burs in 1937 samples was 54.0; the highest 85.3. The lowest percentage of filled burs in 1938 samples was 36.97; the highest 69.0. A comparison of average percentages of the maximum germination obtained from each sample and the average caryopsis counts both for 1937 and 1938 showed a close agreement. The 1937 caryopsis count of 72.4% agreed within 10.0% with the germination of 67.9%. The 1938 caryopsis count of 57.69% agreed with the germination of 52.4%.

A further point of interest in connection with the caryopsis count was the number of caryopses contained in each bur. For this examination 50 burs from each of five samples and 170 burs from a sixth sample were dissected (after soaking in water for 3 hours). The following proportions were obtained: Burs with sound caryopses, 66.5%; burs entirely empty, 10.6%; and burs entirely diseased, 22.9%. The percentage of burs with one or more grains diseased was 10.9. Of the burs with sound caryopses (average of four samples) there were 24.0% with one sound caryopsis, 43.0% with two sound caryopses, and 14.5% with three to four sound caryopses.

Of the burs which contained both healthy and diseased caryopses, the sound caryopses germinated normally and were not affected by the presence of the diseased grains.

GERMINATION

During 1935–36, while the writer was stationed at the Federal Seed Laboratory in Washington, D. C., for the first time a number of samples of buffalo grass seed were received for test. Since no methods of testing this seed were available, trials with various temperatures and substrata were made.

Burs were tested in Petri dishes, in quadruplicates of 100, 2×100, or in a few instances, 2×50 seeds, by any one method, depending on the amount of seed available. Tests were incubated at one or more of the following alternations: 15°–25° C, 10°–35° C, 20°–30° C with daylight, 20°–35° C, room temperature (approximately 20° C)–35° C, and room temperature–30° C, with a daily exposure of 7 hours to the higher temperature and of 17 hours to the lower temperature. Additional tests were made in the greenhouse. As germination was more consistently higher at the room–35° C or 20°–30° C daylight alternations, the room–35° C temperature alternation was chosen as the "check" because exposure to daylight (favorable to the germination of most grasses) was possible, because speed of germination was increased with the slightly higher temperature, and because tests incubated at the 20°–30° C daylight alternation frequently suffered from the excess moisture present in a daylight germinator.

In addition to tests at the above temperatures, the effect of pre-chilling (at 3°–5° C) and of chilling (at 3°–5° C) after a period at higher temperatures were studied (Table 2). Sample 758113, which was immature and greenish in appearance, germinated 3.5% without pre-treatment. When chilled for 3 months this percentage was increased to 36.0. In another test pre-chilled for 1 month 47.0% of the burs sprouted. Sample 758304, with a germination of 19.3% without pre-treatment, showed an increase to 61.3% after 3 months' chilling.

TABLE 2.—*Effect of chilling on the germination of a sample (No. 758307) of buffalo grass which was mature but not weathered.**

Date tested	Method†	Percentage of sprouts		Total germination %
Aug. 29, '35	20°–30° C DL, soil	7.5	Then chilled 3 mo. at 5° C	37.0
Sept. 19, '35	Room–35° C toweling	6.0	Then chilled 3 mo. at 5° C	48.5
			Laboratory	Greenhouse
Oct. 3, '35	Soaked overnite:			
	In KNO_3		7.0	14.5
	In H_2O		11.5	22.0
	Check		6.0	12.5

October 17, 1935

Treatment	Temperature and method	Percentage of germination	
		Soil	Peat and soil
Check (none)	15° C	1.5	1.0
Check	20°–30° C DL	11.5	8.5
Check	Room–35° C	28.0	13.0
Stratified:			
2 weeks at 5° C	Room–35° C	14.0	13.5
3 weeks at 5° C	Room–35° C	16.0	14.0
4 weeks at 5° C	Room–35° C	21.5	16.5
2 months at 5° C	Room–35° C	29.0	32.0
3 months at 5° C	Room–35° C	31.0	50.0
2 weeks at 10° C	Room–35° C	18.0	11.0
3 weeks at 10° C	Room–35° C	15.5	9.5
4 weeks at 10° C	Room–35° C	25.5	21.0
2 months at 10° C	Room–35° C	21.0	26.0
3 months at 10° C	Room–35° C	48.0	26.0

February 11, 1936

Treatment	Germination temperature					
	Room–35° C		15°–25° C		Room–30° C	
	Soil	Peat and soil	Soil	Peat and soil	Soil	Peat and soil
Check (no treatment)	16.5	17.5	8.0	6.0		
Stratified at 5° C:						
1 month	9.0	24.5	25.0	11.5		
2 months	65.0	49.5	50.0	36.0		
3 months	46.0	61.0	—	—	52.5	57.5
4 months	54.0	63.0	—	—	43.5	51.0‡
6 months	34.0	54.0	—	—	34.5	39.0

*All tests germinated 4 × 50 in Petri dishes at temperatures as stated. Room temperature was approximately 20° C from Aug. to Oct.; lower in Feb.
†DL = Daylight, 7 hours; 20° C, 17 hours. Room–35° C: Room, 17 hours; 35° C, 7 hours.
‡Quadruplicates very variable.

A parallel pre-chilled test germinated 36.0%. Sample 758307, mature but not weathered, fluctuated from 6.0% to 28.0% germination without pre-treatment; and from 29.0% to 65.0%, with 2 to 6 months' chilling (Table 2). Samples 271117, 758114, and 759304, weathered in appearance, germinated 66.7%, 74.7%, and 82.0%, respectively, without chilling.

The effect on weathered burs of pre-soaking overnight in tap water or in a 0.2% KNO_3 solution was in one instance definitely stimulating to germination. Among unweathered lots there was no increased response. More recent pre-soaked tests of weathered seed indicated in some cases a favorable reaction (Table 3).

The type of substratum was found in early tests to be especially important to the germination of buffalo grass. A Room–35° C test using toweling (sample No. 271117) as the substratum yielded 35.5% of sprouts. When the seed remaining ungerminated was transferred to sterilized soil, germination increased to 64.0%. A parallel soil test germinated 66.7%. In another sample (No. 758114) the Petri-towel test produced 49.2% of sprouts and the soil test 64.5%. This stimulating effect produced by soil on buffalo grass germination is believed by the writer to be the result of a more favorable moisture relation between the seed and the soil.

As there were usually a variable number of burs containing sound caryopses remaining ungerminated at the termination of each test, a number of caryopses were removed and germinated. In one test (No. 271117) of 25 hulled grains, 13 germinated at once and 11 more after the pericarp was punctured. In another test of 33 dormant caryopses, all germinated when the pericarp was punctured. Thus it appears that the pericarp of dormant grains must be weakened by soil chemicals, temperatures, or organisms before germination can take place.

The indications from the treatments and methods employed in preliminary trials as outlined are that burs harvested from late summer to early spring, which appear to be well weathered, germinate far better and show fewer dormant caryopses than samples harvested green or barely mature. Since burs which were greenish or straw-colored in appearance did not germinate readily without considerable pre-treatment, the possibility that a period of weathering is essential in inducing maximum germination is suggested.

In the weathered samples the greatest number of sprouts occurred during the first week, some the second week, and only an occasional sprout thereafter. In chilled tests the maximum number of seedlings occurred during the first week after removal from the refrigerator. No germination occurred in the refrigerator either at 3°–5° C or at 10° C.

From these preliminary trials a definite schedule of procedure in testing buffalo grass was set up at the San Antonio Seed Laboratory. All burs were germinated in quadruplicates of 50 or 100 in a mixture of 1 part each of sterilized peat, sand, and local black soil in Petri dishes. The daily temperature alternation was 35° C from 9 a.m. to 4 p.m. and room temperature from 4 p.m. to 9 a.m. Check tests were germinated at this alternation with no pre-treatment. Chilled tests

were placed in the refrigerator at 3°–5° C for 4 days to 1 week, for 2 weeks, for 4 weeks, and some for 8 weeks, then germinated at the same temperature alternation as the check test. The duration of tests was 2 months.

During 1937 and 1938 the figures obtained for freshly harvested lots tested at the San Antonio Seed Laboratory followed the trend of germination of the Washington trials.

No conclusive data have yet been accumulated, because the wide variation in degree of maturity of the burs in a given sample and the difficulty in maintaining at all times a uniformity of moisture in the soil substratum were apparently responsible for variation in germination. Hence, all averages in Table 3 should be considered as tentative.

In 1937, the germination of the eight samples of buffalo grass harvested in Texas, which were weathered or partly weathered, averaged as follows:

Caryopsis count	72.4%
Germination of check test	49.7%
Germination after chilling 4 days to 1 week	51.0%
Germination after chilling 2 weeks	58.1%
Germination after chilling 4 weeks:	
Tested immediately	60.5%
Tested 2 months later	70.1%
Germination after chilling 8 weeks	70.3%

In 1938, the averages of five Texas samples tested were as follows:

Caryopsis count	57.7%
Germination of check test	35.1%
Germination after chilling 1 week	44.1%
Germination after chilling 2 weeks	44.7%
Germination after chilling 4 weeks	47.6%

Tests of 44 hand-gathered samples from Spur, Texas, which were immature, or mature but not weathered, gave the following averages:

Caryopsis count	78.68%
Germination of check test	3.18%
Germination after 1 month's chilling	9.61%

In addition, the average number of burs which produced one, two, or three to four sprouts per bur, obtained from the chilled tests of eight samples, was as follows:

Burs with 1 sprout per bur	38.5%
Burs with 2 sprouts per bur	23.9%
Burs with 3 or 4 sprouts per bur	4.3%
Total germination	66.7%

SUMMARY AND CONCLUSIONS

From the foregoing data, it is evident that the establishment of a good stand of buffalo grass from seed is strongly influenced by the character of the seed material. A poor seed set indicates a low percentage of burs which contain caryopses. Difficulty in harvesting

TABLE 3.—*The effect of various chilling treatments on the germination of buffalo grass.**

Lab. No.	Date harvested	Caryopsis count	Date tested	Check test, %	Chilled 1 week, %	Chilled 2 weeks, %	Chilled 4 weeks, 1st test, %	Chilled 4 weeks, 2nd test, %	Chilled 8 weeks, %
				Harvest of 1937					
S-74 . . .	July 4, '37	78.0	Oct. 27, '37	34.0	42.0†	62.0	53.5	—	—
			Dec. 10, '37					66.5	61.0
S-197 . . .	Aug. 14, '37	76.0	Oct. 26, '37	58.0	47.0†	66.0	66.5		
			Dec. 10, '37					74.5	75.5§
S-198 . . .	Aug. 14, '37	76.0	Oct. 26, '37	52.0	71.0†	65.0	63.5		
			Dec. 10, '37					64.0	73.0
S-199 . . .	Sept. 30, '37	54.0	Oct. 26, '37	51.5	45.0†	45.0	37.5		
			Dec. 10, '37					55.0	—
S-205 . . .	Sept. 30, '37	85.3	Oct. 28, '37	32.0	43.0†	51.0	70.0		
			Dec. 10, '37					81.0	83.0
S-229 . . .	July 17, '37	76.5	Jan. 4, '38	57.5	64.0	60.0	75.0		68.0 (2½ months)
S-249 . . .	Jan. 31, '38	61.0	Feb. 15, '38	51.5	—	—	58.7		
			April 19, '38	28.0‡				55.0	
S-250 . . .	Feb. 28, '38	72.0	Mar. 5, '38	61.5	—	—	59.5		61.5
Averages		72.4		49.7	51.0	58.1	60.5	70.1	70.3
				Harvest of 1938					
S-295 . . .	Aug. 16, '38	56.14	Aug. 31, '38	9.5	—	18.5			
			Dec. 4, '38				40.5		42.5**
			Feb. 15, '39	29.0‡	20.0	33.5‡		46.5	
S-297 . . .	Aug. 16, '38	36.97	Oct. 25, '38	33.0	34.5	39.5	32.5		
			Dec. 14, '38						24.7**
S-302 . . .	Sept. 17, '38	68.2	Oct. 24, '38	46.0	48.0	58.5§	56.5		
			Jan. 15, '39		35.5‡	54.0‡		55.0	53.0 KNO_3**
S-303 . . .	Sept. 17, '38	69.0	Oct. 24, '38	39.5	49.3	65.5	64.0		
S-606 . . .	Oct. 29, '38	58.15	Feb. 16, '39	47.5	39.0§	41.5	54.5§		
Averages		57.69		35.1	44.1	44.7	47.6		

*All tests germinated 4×50 in soil in Petri dishes. Duration of tests, 2 months, or for one month after chilling.
†Chilled 4 days.
‡Not averaged.
§Variation between quadruplicate counts more than 10.0%.
**Soaked overnight, not chilled.

material from the ground results in a low percentage of burs in the harvested material. Harvesting before burs are mature and have been weathered results in low germination when planted.

Burs which were at least partially weathered in appearance were made to germinate in the laboratory to within 10.0% of seed set or caryopsis count, either without treatment, or by soaking, or by chilling.

Burs which were immature and greenish, or mature but not weathered, gave increased germination after prolonged chilling or after warm stratification followed by cold treatment. A series of 44 such samples proved rather conclusively that the profound dormancy of this seed cannot be overcome appreciably without prolonged chilling at least for more than a month. Harvesting burs after a period of natural weathering is therefore recommended.

Optimum germination tests were made in sterilized soil in Petri dishes at a daily temperature alternation of 20°–30°, or 20°–35° C, with light, and required 6 to 8 weeks. No germination took place at or below 10° C (50° F). Dormant grains were made to germinate by puncturing the pericarp.

Of burs examined, the majority contained one or two caryopses per bur, a few contained three or four. In germination tests the majority of burs germinating produced one or two seedlings, a small percentage three or four. When diseased and healthy grains were present in the same bur, the germination of the healthy grains was in no way changed.

The presence on occasional plants and also in most seed samples of nematode galls suggests a disease widespread in Texas and of possible economic importance.

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THE ELIMINATION OF DIFFERENCES IN INVESTMENT IN THE EVALUATION OF FERTILIZER ANALYSES[1]

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THE most desirable fertilizer analysis for the farmer to use produces the most profit per dollar invested. Fertilizer analyses tests have usually been conducted using a definite rate of each analysis fertilizer per acre. In most of the tests conducted in Mississippi, 600 pounds per acre of the different analysis fertilizers have been used. The home-mixed costs of 600 pounds of the different fertilizer analyses vary from $5.00 to $9.02.

When used at a definite rate per acre, often ferrilizers of high analysis and high cost produce the most profit per acre and the least profit per dollar invested, while fertilizers of low analysis and low cost produce the least profit per acre and the most profit per dollar invested.

If the tests had been conducted using a definite amount of money invested in each analysis instead of a definite rate per acre of each analysis fertilizer, the fertilizer which would return the farmer the most profit per dollar invested could be determined easily. Where fertilizer analysis tests have been conducted using a definite rate per acre of each analysis, it is desirable to eliminate the differences in cost before calculating the profit per dollar invested.

Where a rate of one analysis fertilizer test has been conducted in conjunction with the test of different analyses, as has been the case in Mississippi, the data on rates may be used to eliminate differences in cost of the different analyses. The purpose of this paper is to present a method for eliminating differences in investment in the evaluation of fertilizer analyses, from which the fertilizer analysis which will return the farmer the most profit for the expenditure of a definite amount of money for fertilizer may be determined.

SOURCE OF DATA

The data used for the calculations presented in this paper were obtained from Mississippi Agricultural Experiment Station Bulletin 289, 1930, "Commercial Fertilizers for Cotton, 1925–1930". Weighted averages were made of the tests conducted in each soil area of the State. The data are reported in Table 1.

METHOD OF CALCULATION

The increase in yield of seed cotton from the application of 600, 1,200, 1,800, and 2,400 pounds per acre of 4–8–4 fertilizer for each soil area was plotted on graph paper. Both "factory-mixed" and "home-mixed" costs of the fertilizer were plotted with the corresponding rate. The increase in yield in pounds of seed cotton per acre was

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TABLE 1.—*The cost of fertilizers, and increase in yield of seed cotton in Mississippi analyses and rates tests, 1925–1930.*

Rate and analysis	Cost of fertilizer		Increase over no fertilizer, pounds seed cotton per acre						
	Factory mixed	Home mixed	Limestone upland	Sandy loam bottom land	Flatwoods upland	Shortleaf pine upland	Longleaf pine upland	Brown loam upland	Av. of non-limestone upland*
Varying Potash									
600 lbs. 4–8–0	$7.21	$5.34	297	162	354	493	414	361	420
600 lbs. 4–8–2	7.59	5.80	311	357	374	549	492	475	472
600 lbs. 4–8–4	7.97	6.32	281	477	401	561	472	577	478
600 lbs. 4–8–6	8.34	6.82	274	532	417	586	473	511	492
600 lbs. 4–8–8	8.72	7.31	299	587	457	567	407	498	477
Varying Phosphorus									
600 lbs. 4–4–4	7.24	5.00	329	400	325	564	387	360	425
600 lbs. 4–6–4	7.60	5.66	337	462	383	582	414	400	460
600 lbs. 4–8–4	7.97	6.32	281	477	401	561	472	577	478
Varying Nitrogen									
600 lbs. 4–8–4	7.97	6.32	281	477	401	561	472	577	478
600 lbs. 6–8–4	9.05	7.67	447	499	480	747	484	491	570
600 lbs. 8–8–4	10.14	9.02	533	484	576	774	539	564	630
Varying Rates of 4–8–4									
600 lbs. 4–8–4	7.97	6.32	281	477	401	561	472	577	478
1,200 lbs. 4–8–4	15.94	12.64	528	725	662	861	686	618	736
1,800 lbs. 4–8–4	23.91	18.96	654	798	748	1024	730	746	834
2,400 lbs. 4–8–4	31.88	25.28	767	848	828	1067	704	833	866
Yield without fertilizer			571	829	329	471	670	618	490

*Except brown loam.

plotted on the vertical axis; the rate of application of fertilizer and the costs per acre were plotted on the horizontal axis. Then a line of best fit was drawn for the data. The costs of the fertilizers were based on local prices of mixed fertilizers, nitrate of soda, superphosphate, and muriate of potash. The line of best fit was represented by the type of equation $Y=a+bX+cX^2$.

Where Y = increase in yield per acre, X = amount of fertilizer applied per acre, and a, b, and c are constants of the equation. The part of the curve below 600 pounds per acre of 4–8–4 fertilizer was drawn in with a french curve. The line may be drawn in free hand or by use of a french curve; the line so drawn is nearly as accurate as the calculated line of best fit.

The plotted curve represents the increase in yield for 4–8–4[3] at any rate from 0 to 2,400 pounds per acre. The curve is reliable between slightly below the 600 and 2,400 pound rates per acre, which was the part of the curves used in arriving at the calculations reported in this paper. All of the fertilizer analyses were applied at the rate of 600 pounds per acre.

The relative value of 4–8–4 and other analyses was determined by reading from the curve the amount of seed cotton which would have been produced by the same amount of money invested in 4–8–4 as was invested in 600 pounds of the analysis in question. The values so obtained were used to calculate the amount of seed cotton which would have been produced by $100.00 worth of the fertilizer applied to 12.55 acres, from which the profit per $100.00 invested was calculated using a value of three and one-half cents per pound for seed cotton.

The average increase in yield obtained from the use of different analysis fertilizers and rates of 4–8–4 in the different soil areas are reported in Table 1. The increases in yield and profits from $100.00 invested in different analysis fertilizers are reported in Tables 3 and 4, respectively.

RESULTS AND DISCUSSION

The shortleaf pine data (Fig. 1) are used to illustrate the application of the method for eliminating differences in investment in fertilizer analyses. The calculations are accumulated in Table 2. The increases in yield produced by 600 pounds per acre of the different analyses are recorded in column 4; in columns 5 and 6, the yield which would have been obtained from the application of 4–8–4 costing the same amount as 600 pounds of the different factory-mixed and home-mixed fertilizers is recorded. These yields were obtained from the curve. As an illustration, 600 pounds of factory-mixed 4–4–4 cost $7.24 and produced 564 pounds of seed cotton. From the curve, it is found that $7.24 worth of 4–8–4 produced 530 pounds of seed cotton. With $7.24 invested in factory-mixed 4–4–4 and in 4–8–4, the increase in yield was 564 and 530 pounds of seed cotton, respectively. Where equal costs are involved, differences in investment are eliminated. The application of $100.00 worth of 4–8–4 at $7.97 per acre on 12.55 acres produced 7,039 pounds of seed cotton. With $100.00 invested in 4–4–4, the increase in yield was 7,039×

[3] N, P_2O_5, and K_2O, respectively.

TABLE 2.—*Data used in the elimination of differences in investment in the evaluation of fertilizer analyses tests, shortleaf pine upland.*

Analysis	Cost of fertilizer		Increase in yield, pounds seed cotton per acre	Calculated increase in yield—same cost in 4–8–4*		Increase yield per $100.00 invested		Profit per $100.00 invested	
	Factory mixed	Home mixed		Factory	Home	Factory	Home	Factory	Home
4–8–0	$7.21	$5.34	493	530	505	6,548	7,974	$129.18	$179.09
4–8–2	7.59	5.80	549	550	533	7,026	8,413	145.91	194.46
4–8–4	7.97	6.32	561	—	—	7,039	8,168	146.37	185.88
4–8–6	8.34	6.82	586	585	594	7,051	8,058	146.79	182.03
4–8–8	8.72	7.31	567	600	615	6,652	7,530	132.82	163.55
4–4–4	7.24	5.00	564	530	484	7,491	9,518	162.19	233.13
4–6–4	7.60	5.66	582	548	527	7,476	9,020	161.66	215.70
6–8–4	9.05	7.67	747	612	635	8,592	9,609	200.72	236.32
8–8–4	10.14	9.02	774	663	707	8,217	8,942	187.60	212.97

*The increases in yield for 4–8–4 fertilizer costing the same as the different analysis fertilizers were obtained from the curves.

TABLE 3.—*Calculated increase in yield of seed cotton per $100.00 invested in cotton fertilizers applied to 12.55 acres.*

Analysis	Limestone soils		Silt and sandy loam bottom		Flatwoods uplands		Shortleaf pine upland		Longleaf pine upland		Average shortleaf pine, longleaf pine, and flatwood uplands	
	Factory mixed	Home mixed	Factory mixed	Home mixed	Factory mixed	Home mixed	Factory mixed	Home mixed	Factory mixed	Home mixed	Factory mixed	Home mixed
4–8–0	3,997	5,324	2,126	2,558	4,662	5,866	6,548	7,974	5,400	6,553	5,572	6,735
4–8–2	4,032	5,194	4,546	5,391	4,764	5,860	7,026	8,413	6,266	7,407	6,048	7,205
4–8–4	3,526	4,392	5,985	6,901	5,031	6,048	7,039	8,168	5,922	6,775	5,997	6,976
4–8–6	3,253	3,933	6,432	7,199	4,948	5,798	7,051	8,058	5,717	6,435	5,961	6,770
4–8–8	3,423	4,041	6,862	7,716	5,249	6,115	6,652	7,530	4,801	5,365	5,598	6,326
4–4–4	4,428	6,282	5,262	6,636	4,247	5,616	7,491	9,518	5,037	6,303	5,602	7,231
4–6–4	4,353	5,759	5,883	7,023	4,854	6,080	7,476	9,020	5,261	6,317	5,894	7,131
6–8–4	4,956	5,724	5,732	6,377	5,390	6,177	8,592	9,609	5,620	6,187	6,548	7,309
8–8–4	5,339	5,972	5,038	5,642	6,000	6,686	8,217	8,942	5,889	6,351	6,747	7,300

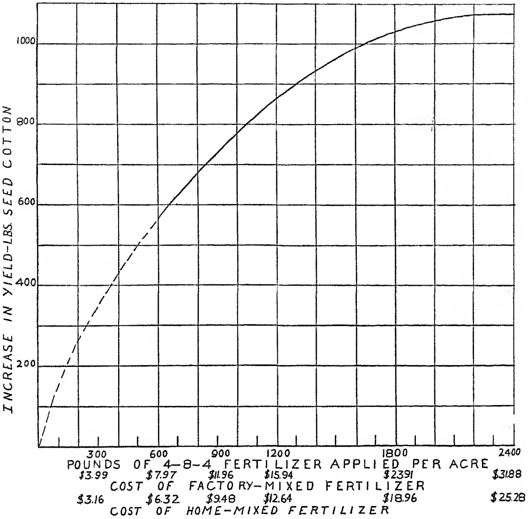

FIG. 1.—The relation of rate of application and investment in 4–8–4 fertilizer to the increase in yield of seed cotton on the shortleaf pine soils.

564÷530 or 7,491 pounds of seed cotton. The profit was determined by multiplying the pounds of seed cotton by three and one-half cents and subtracting $100.00.

In the elimination of differences in investment between factory-mixed and home-mixed fertilizers, the rate of application per acre was higher for the home-mixed fertilizer due to the fact that home-mixed fertilizers were cheaper. Consequently, the calculation for the increase in yield for $100.00 worth of home-mixed 4–8–4 was based upon the increase in yield from $7.97 worth of home-mixed fertilizer per acre applied to 12.55 acres. The increase in yield for $7.97 worth of home-mixed 4–8–4 fertilizer was obtained from the curve and multiplied by 12.55 which gives 8,168 pounds of seed cotton. The increase in yield from $5.00 worth of home-mixed 4–4–4, and 4–8–4 was 564 and 484 pounds of seed cotton per acre, respectively. The increase in yield for $100.00 worth of home-mixed 4–4–4 was found to be 8168×564÷484=9,518 pounds of seed cotton. Multiplying 9,518 pounds by the value of seed cotton (3½ cents per pound) and subtracting $100.00 gives a profit of $233.13.

TABLE 4.—*Calculated profit per $100.00 invested in cotton fertilizers applied to 12.55 acres.*

Analysis	Limestone upland		Silt and sandy loam bottom		Flatwoods		Shortleaf pine upland		Longleaf pine upland		Average shortleaf pine, longleaf pine, and flatwoods uplands	
	Factory mixed	Home mixed	Factory mixed	Home mixed	Factory mixed	Home mixed	Factory mixed	Home mixed	Factory mixed	Home mixed	Factory mixed	Home mixed
4–8–0	$39.90	$ 86.34	$–25.59	$–10.47	$ 63.17	$105.31	$129.18	$179.09	$ 89.00	$129.36	$ 95.02	$135.73
4–8–2	41.12	81.79	59.11	88.69	66.74	105.10	145.91	194.46	119.31	159.25	111.68	152.18
4–8–4	23.41	53.72	109.48	141.54	76.09	111.68	146.37	185.88	107.27	137.13	109.90	144.16
4–8–6	13.86	37.66	125.12	151.97	73.18	102.93	146.79	182.03	100.10	125.23	108.64	136.95
4–8–8	19.81	41.44	140.17	170.06	83.72	114.03	132.82	163.55	68.04	87.78	95.93	121.41
4–4–4	54.98	119.87	84.17	132.26	48.65	96.56	162.19	233.13	76.30	120.61	96.07	153.09
4–6–4	52.36	101.57	105.91	145.81	69.89	112.80	161.66	215.70	84.14	121.10	106.29	149.59
6–8–4	73.46	100.34	100.62	123.20	88.65	116.20	200.72	236.32	96.70	116.55	129.18	155.82
8–8–4	86.87	109.02	76.33	97.47	110.00	134.01	187.60	212.97	106.12	122.29	136.15	155.50
Best analyses	8–8–0* 6–8–4†	4–4–0* 8–8–0*	4–8–8	4–8–8	8–8–4 6–8–4†	8–8–4	6–8–4	4–4–4 6–8–4	4–8–2 4–8–4† 8–8–4	4–8–2	8–8–4 6–8–4	4–8–2 4–4–4 4–6–4 6–8–4 8–8–4

*Other data are available which show an 8–4–0 to be as profitable for these soils as an 8–8–0. Potash was omitted because it was not needed.
†Best analysis which can be bought mixed.
In the brown loam area a 4–8–4 has given the best results. $100.00 worth of home-mixed fertilizer was equal to $126.04 worth of factory-mixed fertilizer on brown loam soils.

With the differences in investment in fertilizer analyses eliminated, it is possible to point out relations between the response to analyses which do not show up with the usual interpretation. The 4–8–2 analysis was definitely more profitable than the 4–8–0 and 4–8–8, and practically as profitable as 4–8–4 and 4–8–6. Factory-mixed 4–4–4 produced a profit of $162.19 and 8–8–4 produced a profit of $187.60. Where the fertilizers were home-mixed, the 4–4–4 made a profit of $233.13 and the 8–8–4 made $212.97. $100.00 worth of 4–4–4 and 6–8–4 made profits of $162.19, and $200.72 when factory-mixed, and $233.13 and $236.32 when home-mixed, respectively. Where phosphorus varied, phosphoric acid equal to the nitrogen was as profitable or more profitable than higher ratios of phosphorus to nitrogen.

The limestone upland soils did not respond to potash, but they gave excellent responses to nitrogen. On the basis of the data presented, the best analysis with factory-mixed fertilizers was an 8–8–4, and with home-mixed fertilizers, 4–4–4 or 8–8–4. However, other data are available which show that 8–8–0 and 8–4–0 are equally profitable for these soils.

The sandy loam and silt loam bottom soils were very responsive to potash and phosphorus. The best analysis was a 4–8–8.

The longleaf pine soils were more responsive to a 4–8–2 than to any other fertilizer. It should be borne in mind that the fertilizers used in these tests were: nitrate of soda, superphosphate, and muriate of potash. When fertilizers were home-mixed, the 4–8–2 fertilizer made $22.12 more per $100.00 invested in fertilizer than did 4–8–4 and all other analyses made less profit than did 4–8–4.

The ratio of nitrogen to potash in the 4–8–2 analysis is the same as that in the 8–8–4, and practically the same as that in the 6–8–4. These soils responded to high amounts of superphosphate. The high response to superphosphate is due, partly at least, to the extremely acid condition of the soils. Under these conditions, superphosphate supplies calcium as a nutrient to the crops. On the basis of the work conducted at other places in the State, liming should reduce the superphosphate requirement of these soils and the analysis should then fall within the range of other less acid soils which give the best response to a 6–8–4 or an 8–8–4.

The average of the data for the flatwoods, shortleaf pine and longleaf pine uplands is probably a better generalization for these soils than the data for the separate areas unless lime should reduce the phosphate requirement on the strongly acid soils. When the fertilizers were factory-mixed, the 8–8–4 was slightly superior to the 6–8–4 analysis, and these analyses were superior to all others. When the fertilizers were home-mixed and $100.00 worth of fertilizers used a 4–8–2, 4–4–4, 4–6–4, 6–8–4, and 8–8–4 were almost equally profitable.

The brown loam upland data would not lend themselves to the statistical treatment, and no analysis was superior to a 4–8–4.

HOME-MIXED VERSUS FACTORY-MIXED FERTILIZERS

When fertilizers were home-mixed, 26% more fertilizer was obtained for the expenditure of a definite amount of money for 4–8–4 fertilizer than when they were bought factory-mixed. In considering

only the best factory-mixed and the best home-mixed analyses for each soil area, the expenditure of $100.00 for home-mixed fertilizer resulted in the following profits over the same amount of money invested in factory-mixed fertilizers:

Limestone upland	$33.00
Bottom land	29.89
Flatwoods upland	24.01
Shortleaf pine upland	35.60
Longleaf pine upland	39.94

The relative difference between the profit obtained with the use of different factory-mixed analyses will approach that obtained with the home-mixed analyses when the analyses of the factory-mixed fertilizers are increased (maintaining the same ratio) to 20 units of plant nutrients. The reason for this is that the cost of the fertilizing constituents is less in the higher analysis fertilizers.

SUMMARY AND CONCLUSIONS

Fertilizer analyses tests are usually conducted on the basis of a given number of pounds per acre of the different analysis fertilizers. Where the percentages of nitrogen, phosphoric acid, and potash vary, there is in reality a rates test of all three elements. Where rates vary, the operation of the law of diminishing returns may prevent the interpreter from arriving at the analysis from which the farmer will obtain the most profit for the money invested in fertilizers. A method was presented for calculating the analysis from which a farmer would obtain the most profit for a definite amount of money invested in fertilizers. The method of eliminating differences in investment is based upon the data obtained from a rates of one analysis test which is conducted in conjunction with the analysis test. The data are plotted and a curve of best fit is drawn. From the curve, the increase in yield from fertilizer equal in cost to the analysis fertilizer being compared with the plotted analysis fertilizer is obtained. With equal costs the best fertilizer may be determined and the calculations made for any convenient investment in fertilizer.

GERMINATION OF SEED OF VINE-MESQUITE, *PANICUM OBTUSUM*, AND PLAINS BRISTLE-GRASS, *SETARIA MACROSTACHYA*[1]

Vivian K. Toole[2]

VINE-MESQUITE, *Panicum obtusum*, H. B. K. and plains bristle-grass. *Setaria macrostachya*, H. B. K. are perennial grasses of the southwest; the former species having the wider distribution. *Panicum obtusum* grows in moist places and *Setaria macrostachya* grows in dry ground. Hoover (6)[3] refers to the use of *Panicum obtusum* in erosion control work. He states that seed collected from natural stands was often of low quality and did not germinate well. Since difficulty had been encountered with these 2 species in obtaining field stands from seedings and in obtaining complete germination of the viable seed in the laboratory a study was made to determine how much the poor germination was due to resistance to germination and how much was due to poor quality. The results presented are based on too few samples to be considered conclusive, but should be suggestive to future workers on the germination of these species.

Wilson (15) obtained an average germination of 2% over a 6-year period on seed of *Panicum obtusum*. He germinated the seed at 20° C to 30° alternation for a 30-day period.

Jackson (8) obtained as high as 30% germination on *Panicum obtusum* at 25° C.

Burton (2) found treatment with crude sulphuric acid beneficial for the germination of some southern grasses of the tribe *Paniceae*. Hiltner (5), Harrington (3, 4), Morinaga (9), Bryan (1), Stoddart and Wilkinson (11), and Huntamer (7), have reported on the beneficial effect of treating other grass seed with concentrated sulphuric acid. Toole (12), (13), (14) found approximately 71% by volume (approximately 80% by weight) sulfuric acid beneficial for some grass seed.

MATERIAL AND METHODS

The seed used in these studies was furnished through the courtesy of M. M. Hoover of the Soil Conservation Service. The historical data on the samples is given in Table 1. The seed as received was separated by an air blast blower and sieves into two groups, *viz.*, (a) empty and immature florets, and (b) heavy, filled florets or mature seed. The approximate purity, that is, the percent of mature seed, of the samples of *Panicum obtusum* as received varied from 20 to 98%. The samples were stored in paper bags in the laboratory for the duration of the experiment. Only the mature seed was used in this study. "Seed" as used in this paper includes the caryopsis, the chartaceous-indurate lemma and palea, and the herbaceous glumes.

[1]Contribution from the Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. This work was conducted in the former Division of Seed Investigations, Bureau of Plant Industry. Received for publication March 25, 1940.

[2]Junior Botanist.

[3]Figures in parenthesis refer to "Literature Cited", p. 512.

The seed was pretreated and germinated according to the methods described in the paper "The germination of seed of *Oryzopsis hymenoides*" (14). Germination results summarized in Tables 2 to 8 are in all cases mean values, based on duplicate tests of 100 seeds each. In Table 5, half percents have been raised to the next higher percentage. Values for tests of significance of differences have been calculated by the analysis of variance method as adapted by Snedecor (10).

TABLE 1.—*Descriptive data on all samples of seed.*

Sample No.	Date of collection	Place of collection	Date received in laboratory	Notes by collector	Approximate purity of sample %
		Panicum obtusum			
761229	———	Texas	July 17, '36	———	—
766605	———	———	Nov. 3, '37	———	—
766902	Crop of 1937	Yukon, Okla.	Dec. 17, '37	———	20
766905	Oct. 21, '37	Wildorado, Tex.	Dec. 17, '37	Obtained from drainway bottom along railroad	24
766907	Oct. 31, '36	Mountainair, N. M.	Dec. 17, '37	Collected with hand strippers at elevation of approximately 6,000 feet	33
767285	Nov. 26, '37	Cowans Ranch, McNeal, Ariz.	Jan. 10, '38		98
		Setaria macrostachya			
761228	———	Nursery, Tucson, Ariz.	July 17, '36		—
767279	Aug. '37	Nursery, Tucson, Ariz.	Jan. 10, '38		76

VINE-MESQUITE

GERMINATION TEMPERATURE

Four samples of *Panicum obtusum* were germinated in soil in Petri dishes at constant temperatures of 15°, 20°, 25°, 30°, and 35° C and at alternating temperatures of 15° to 25°, 20° to 30° with light,[4] 10° to 35°, 35° to 10°, room temperature to 35°, 20° to 35°, 20° to 40° and 25° to 40°. The results are given in Table 2. The mean germination of the four samples shows that alternating temperatures

[4]Definite light exposure at 30° in glass enclosed chamber in north window. Other temperature conditions, except room temperature to 35°, did not have definite light exposure but light was not excluded.

are superior to constant temperatures for the germination of seed of *Panicum obtusum*.

The seed germinated approximately the same at a wide range of alternating temperatures that include the lower temperature for the longer period of the alternation. The 35° to 10° alternation was significantly poorer and the room temperature to 35° alternation was significantly better than the other alternating temperatures tried. The room temperature to 35° alternation did not produce complete germination of the viable seed in 28 days in all cases. With sample 766902 germination appeared to be completed at this temperature in 28 days but with sample 761229 apparently complete germination was not obtained until 70 days. Sample 766905 and 766907 still showed 8 and 10% sound seed respectively at the end of 130 days at alternation of room temperature to 35°. Sample 766905 germinated higher at alternation 20° to 35° than at alternation room temperature to 35° and showed apparently complete germination of the viable seed in 63 days at the former alternation. The mean results of another series of tests given in Table 4 show no significant difference between the alternation room temperature to 25° and 20° to 35° germination temperatures.

POTASSIUM NITRATE

Tests were conducted at eight alternating temperatures with the use of 0.2% solution of potassium nitrate and with water to determine the effect of nitrate on the germination of the seed. The mean results in Table 3 illustrate the beneficial effect from the use of potassium

TABLE 2.—*The 28-day germination in soil in Petri dishes of seed of Panicum obtusum at various temperatures, average of duplicate 100-seed tests.**

Temperature of germination chamber, °C	Percentage germination shown by different samples on indicated dates				
	761229, Aug. 14, 1936	766902, Jan. 13, 1938	766905, Jan. 13, 1938	766907, Jan. 13, 1938	Mean
15°	7.0	19.0	11.0	12.0	12.25
20°	22.0	41.5	22.5	16.5	25.63
25°	31.0	49.0	30.5	9.0	29.88
30°	22.5	53.5	25.0	13.5	28.63
35°	19.5	40.0	20.0	7.5	21.75
15° to 25°	30.0	51.5	47.5	30.5	39.88
20° to 30° with light	30.0	52.5	50.5	32.5	41.38
10° to 35°	36.0	50.5	43.5	36.5	41.63
35° to 10°	27.5	50.0	47.0	15.5	35.00
Room to 35°	50.5 (2)†	72.0 (0)	45.5 (28)	37.5 (13)	51.38
20° to 35°	25.5	64.0	63.0 (8)	13.5	41.50
20° to 40°	23.0	58.5	45.0	34.5	40.25
25° to 40°	26.0	58.5	41.0	30.5	39.00
Mean	26.96	50.81	37.85	22.27	34.47

*According to t test, differences required for significance are: Between means of two observations, 21.39; between means of eight observations, 5.33, 26 observations, 2.76%.

†Figures in parenthesis after percentage of germination show approximate precentage of apparently sound seed remaining at the end of 28 days.

nitrate. It was observed that the papery glumes are readily infected by a black fungus that retards root development and that this was more apparent when the seed was germinated on moistened toweling than when germinated on soil. The combined effect of potassium nitrate and an alternating temperature did not bring about complete germination of all the viable seed, especially of sample 767285. The mean results for both temperatures in Table 4 also show an increased germination from the use of potassium nitrate for untreated seed but not for treated seed.

PRECHILLING

Three samples were prechilled for 14, 28, and 56 days at 3°, 10°, and 15° C before germination at alternation of room temperature to 35°. The results were somewhat inconsistent but there was an indication that prechilling at 3° for 28 days was beneficial on one sample (766907).

TREATMENT WITH SULFURIC ACID

Other writers have shown that grass seeds restricted in their germination by the seed or fruit coat could be made to germinate by altering the coat by means of sulfuric acid treatment. The seed of *Panicum obtusum* was treated with approximately 71% by volume (approximately 80% by weight) sulfuric acid for 0, 30, 60, 90, and 120 minutes. The germination results at alternation of room temperature to 35° C and at 20° to 35° with water and with potassium nitrate show a benefit of acid treatment (Table 4). The means for the two temperatures indicate a highly significant increase of germination for each successively longer treatment up to 90 minutes. These differences are due largely to the results with sample 766907. Sample 761229 and 766605 did not show any marked effect of acid treatment on final germination, but the rate of germination of these samples was increased by treatment (Table 5).

Germination results in soil with two additional samples not given in the table showed a similar benefit from acid treatment. With these samples, removal of the papery glumes by light rubbing with emery paper had no effect on germination.

CHANGE IN RESPONSE WITH AGE

One sample first tested in 1936 and five samples originally tested in January and February 1938 were again tested under the same conditions in January and February 1939. A parallel germination after treatment of the seed with approximately 71% by volume sulfuric acid for 90 minutes was made on each sample at the time of the second test. The results with potassium nitrate are given in Table 5. Sample 761229 had fallen in viability in the period of more than 3 years between the two tests, but the rate of germination of this old seed was hastened by acid treatment. The seed of sample 766902 became more resistant to germination during storage for a year, but it would not appear that viability had fallen as shown by the germination after acid treatment. The response of seed of samples 766605 and 766907

TABLE 3.—*Germination in 28 days of seed of Panicum obtusum at indicated temperatures, February 2, 1938, average of duplicate 100-seed tests.**

Sample No.	Percentage germination at indicated temperatures							
	15°–25°	20°–30°	10°–35°	35°–10°	Room–35°	20°–35°	20°–40°	25°–40°
				Potassium Nitrate				
766605	42.5	40.0	46.5	50.0	51.0	50.0	49.0	56.0
767285	9.5	14.0	13.5	17.0	26.0	12.5	13.5	21.5
Mean	26.0	27.0	30.0	33.5	38.5	31.25	31.25	38.75
				Water				
766605	21.0	26.5	10.0	19.0	28.5	36.5	26.5	28.0
767285	0.0	6.5	1.0	3.5	4.0	7.5	2.0	4.5
Mean	10.5	16.5	5.5	11.25	16.25	22.0	14.25	16.25

*According to t test, differences required for significance are: Between means of two observations 17.70, four observations 7.12%.

TABLE 4.—*Germination in 21 days of seed of Panicum obtusum at two temperatures after indicated treatments, February 8, 1939, average of duplicate 100-seed test.**

Sample No.	Approximate age of seed, years	Percentage germinated at indicated temperatures, °C: Room to 35°, germinated after indicated acid treatment						20 to 35°, germinated after indicated acid treatment					
		0	30	60	90	120	Mean	0	30	60	90	120	Mean
Potassium Nitrate													
761229	4	19.0	23.5	14.5	26.5	20.0	20.7	10.5	22.0	17.0	17.5	14.0	16.20
766605	—	46.5	41.5	47.0	56.0	51.0	48.4	39.0	47.5	49.5	55.0	60.0	50.20
766907	2 1/3	42.0	52.5	79.0	83.0	77.5	66.8	34.0	55.5	67.0	79.5	78.5	62.90
Mean		35.83	39.16	46.83	55.16	49.5	45.30	27.83	41.66	44.5	50.66	50.83	43.10
Water													
761229		20.0	26.0	19.5	23.0	21.5	22.0	21.5	21.0	17.5	21.5	22.5	20.80
766605		39.0	45.0	58.5	62.5	59.5	52.9	38.5	48.0	51.5	61.5	60.0	51.90
766907		25.5	40.5	60.0	64.0	71.5	52.3	21.5	42.0	52.0	58.0	55.0	45.70
Mean		28.16	37.16	46.0	49.83	50.83	42.40	27.16	37.0	40.33	47.0	45.83	39.46
Mean	Means	31.99	38.16	46.41	52.49	50.16	43.85	27.49	39.33	42.41	48.83	48.33	41.28
Mean for 2 temperatures:													
Potassium nitrate		31.83	40.41	45.66	52.91	50.16	44.20						
Water		27.66	37.08	43.16	48.41	48.33	40.93						
Potassium nitrate and water		29.74	38.74	44.41	50.71	49.24	42.56						

*According to *t* test, differences required for significance are: Between means of two observations, 19.77; four observations, 7.95; six observations, 5.91; ten observations, 4.31; twelve observations; 3.89; 24 observations, 2.67%.

TABLE 5.—*Change in response of Panicum obtusum to the alternating temperature, room temperature to 35° C, with age of seed, average of duplicate 100-seed test.*

Sample No.	Date tested	Approximate age when tested	Treatment	Percentage germination after		
				7 days	14 days	21 to 28 days (final)
761229	Aug. 14, '36	1 year	None	46	50	51
	Feb. 8, '39	4 years	None	4	18	19
	Feb. 8, '39	4 years	Sulfuric acid 90 minutes	23	27	27
766902	Jan. 12, '38	3 months	None	11	71	72
	Jan. 17, '39	15 months	None	5	48	50
	Jan. 17, '39	15 months	Sulfuric acid 90 minutes	65	69	69
766605	Feb. 2, '38	———	None	32	49	51
	Feb. 8, '39	———	None	36	46	47
	Feb. 8, '39	———	90 minutes	55	56	56
766907	Jan. 13, '38	15 months	None	8	34	38
	Feb. 8, '39	28 months	None	8	33	45
	Feb. 8, '39	28 months	90 minutes	60	81	83
766905	Jan. 13, '38	3 months	None	13	35	46
	Jan. 16, '39	15 months	None	32	53	54
	Jan. 16, '39	15 months	90 minutes	59	62	62
767285	Feb. 2, '38	3 months	None	2	21	26
	Feb. 8, '39	15 months	None	15	43	47
	Feb. 8, '39	15 months	90 minutes	44	66	68

did not change between the two tests, but the rate and amount of germination at the second test was increased by acid treatment. The germination of seed of samples 766905 and 767285 was appreciably better at the second test but was still further improved both in rate and amount by acid treatment. The results presented do not show a consistent improvement of germination as the seed ages, but whatever the age of the seed, the rate of germination was increased by acid treatment.

PLAINS BRISTLE-GRASS

The results from tests with seed of *Setaria macrostachya* serve only as suggestions for the optimum germination condition for this seed since only two samples were available. The results from tests conducted at various constant and alternating temperatures indicate that alternating temperatures of 35° to 10° C and 10° to 35° are better than the other temperatures tried (Table 6).

The mean germination of seed prechilled at 3° or at 10° is significantly better than the mean germination of seed not prechilled (Table 7). Seed from sample 767279 was also prechilled but was not included in the table as 22% was the highest result obtained.

Seeds were pretreated for 0, 15, 30, 45, and 60 minutes with approximately 71% by volume (80% by weight) sulfuric acid and germinated at alternation 20° to 30° with light with the use of potassium nitrate and water. The mean results show 15 and 30

TABLE 6.—*The germination in 42 days in soil in Petri dishes of Setaria macrostachya at various temperatures, average of duplicate 100-seed tests.**

Sample No.	Date of germination test	Percentage germination after 42 days at indicated temperatures, °C										
		20°	25°	30°	35°	20° to 30° with light	20°–35°	15°–25°	10°–35°	35°–10°	20°–40°	25°–40°
761228...	Aug. 14, 1936	57.5	43.5	6.0	3.0	53.0	47.5	48.0	65.5	67.0	47.0	56.5
767279...	Feb. 4, 1938	6.0	5.0	3.0	8.0	10.5	6.5	5.0	7.5	15.5	2.0	9.5
Mean....		31.75	24.25	4.5	5.5	31.75	27.0	26.5	36.5	41.25	24.5	33.0

*According to *t* test, differences required for significance are: Between means of two observations, 14.25; between four observations, 5.73%.

minutes to be the best treatments and germination was increased by the use of potassium nitrate after these treatments (Table 8).

TABLE 7.—*The germination in 66 days in soil in Petri dishes of seed of Setaria macrostachya after prechilled treatments, sample 761228, August 14, 1936, average of duplicate 100-seed tests.**

Germination temperature, °C	Percentage germination after prechilling at indicated temperature for 2 to 4 weeks				
	3° C		10° C		Check No. prechilling
	2 weeks	4 weeks	2 weeks	4 weeks	
20° to 30° with light	60.0	64.5	60.5	62.0	54
20° to 35°	61.5		59.5		50
20° to 40°	61.0		61.0		48.5
Mean	60.83		60.33		50.83

*According to t test, differences required for significance are: Between means of two observations, 19.81%; six observations, 5.92%.

TABLE 8.—*The germination in 28 days of seed of Setaria macrostachya at 20° to 30° with the influence of potassium nitrate after various pretreatments with approximately 71% sulfuric acid, March 6, 1939, average of duplicate 100-seed tests.**

Sample No.	Treatment of substrata	Percentage germination after indicated acid treatment					Mean
		0 minutes	15 minutes	30 minutes	45 minutes	60 minutes	
761228	Potassium nitrate	37.5	59.0	60.0	40.5	46.0	48.6
	Water	32.0	46.5	43.5	38.0	35.5	39.1
Mean		34.75	52.75	51.75	39.25	40.75	43.85
767279	Potassium nitrate	21.0	44.5	44.5	41.0	23.5	34.9
	Water	26.5	40.5	46.0	42.0	32.0	37.4
Mean		23.75	42.5	45.25	41.5	27.75	36.15
Mean	Potassium nitrate	29.25	51.75	52.25	40.75	34.75	41.75
Mean	Water	29.25	43.5	44.75	40.0	33.75	38.25
Mean	Means	29.25	47.62	48.5	40.37	34.25	40.00

*According to t test, differences required for significance are: Between means of two observations, 15.04; between four observations, 6.04; eight observations, 3.74; sixteen observations, 2.52%.

DISCUSSION

It appears that much of the failure to obtain field stands from seed of *Panicum obtusum* and *Setaria marcostachya* may be due to unfilled or immature florets. However, resistance of the seed coat offers a problem in the germination of the seed as shown by the improved

germination of both species from acid treated mature caryopses. Complete germination of the viable seed was obtained on seed of *Panicum obtusum* after acid treatment. The condition of the non-germinating seed of *Setaria macrostachya* was not determined. The endosperm remained sound in both species. The embryo of *Panicum obtusum* either germinated or decayed. The embryo of *Setaria macrostachya* discolored but did not become soft. It is probable that many of the non-germinating seeds of this species were dormant and that the proper condition for complete germination was not found.

SUMMARY

The alternating temperatures, room temperature to 35° C, or 20° to 35°, were significantly better for the germination of the seed of *Panicum obtusum* than the other alternating or constant temperatures tried. Germination was increased by a dilute solution of potassium nitrate. Pretreatment of the seed with approximately 71% sulfuric acid for 90 minutes overcame the resistance of the seed to germination. There was no consistent improvement of germination with age, but whatever the age of the seed, the rate of germination was increased by acid treatment.

The seed of *Setaria macrostachya* germinated best at alternating temperature of 10° to 35° C or 35° to 10°. The seed was benefitted by prechilling or by pretreating with approximately 71% sulfuric acid for 15 to 30 minutes. Potassium nitrate improved germination.

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SIGNIFICANCE OF ADSORPTION, OR SURFACE FIXATION, OF PHOSPHORUS BY SOME SOILS OF THE PRAIRIE GROUP[1]

W. H. METZGER[2]

PHOSPHORUS fixation by soils has been studied for many years. Much has been learned of the processes whereby phosphorus may be removed from solution by soils to which it is applied. The literature concerning the subject is voluminous but even a cursory perusal of the various publications reveals that there is much yet to be learned concerning at least some of the fixation processes.

Without attempting to review the extensive literature, it shall suffice here to point out that several recent contributors have proposed that, within certain ranges of reaction, at least, phosphorus is adsorptively[3] fixed on the surfaces of clay particles. Representative papers are those of Roszmann (16),[4] Bradfield, Scarseth and Steele (1), Scarseth (17), Mattson (9), Pugh and du Toit (13), and Ravikovitsch (14). Since the alumino-silicate complex of most soils is negatively charged several theories have been offered to explain adsorption of phosphorus. Adsorption through one or more free aluminum valences has been offered as an explanation. Displacement of OH^- groups from an alumino-silicate structure is another explanation, and replacement of 2 Si by a PAl complex has also been proposed. Schofield (18) found that montmorillonitic, kaolinitic, and halloysitic clays have nearly constant electrical charges from pH 6.0 downward. He also found that some other clays (not mineralogically identified) did not behave as the above mentioned types. At low pH values, these clays, he believes, carry positive charges; his results indicated that they adsorb Cl^- from HCl solution. Murphy (11) showed that ground kaolinite possesses high fixing capacity for phosphorus, and that kaolinitic clay is also characterized by high phosphorus fixing capacity. Mattson and Karlsson (10) propose two types of binding by soil colloid particles, in addition to chemical precipitation. In the one type, designated "colloid bound," the phosphorus is presumed to enter into the micellar structure. In the other type, called "saloid bound," the phosphorus, probably as $H_2PO_4^-$, forms an outer circle, or a part of an outer circle, of electrically charged (negative) ions about the micelle, balancing positive charges

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[2]Associate Professor of Soils. That portion of the work reported in this paper which deals with attempts to bring about an equivalent exchange of phosphate by oxalate was done in the laboratories of the Soils Department, University of Wisconsin, where the writer spent the summer of 1938 on sabbatical leave. Gratitude is hereby expressed to the Soils Department for the facilities made available and to Professor E. Truog for counsel and advice.

[3]Throughout this paper fixation of phosphorus at particle surfaces in a replaceable form is referred to as adsorption, while absorption implies some form of chemical precipitation such as precipitation as phosphates of Ca, Mg, Fe, Al, or possibly as certain complex phospho-silicates.

[4]Figures in parenthesis refer to "Literature Cited", p. 525.

in the cationic layer. Toth (21) believed that the reaction involved in displacement of phosphate by silicate, for example, is probably not similar to that of equivalent cation exchange.

REPLACEMENT OF PHOSPHATE BY OXALATE

The first experiments undertaken in the work reported here involved attempts at replacement of adsorbed or surface fixed phosphate from the surfaces of soil particles. Many difficulties were encountered. The two anions most prominently mentioned as effective in replacement of phosphate are the silicate and the hydroxyl ions. Neither lends itself well to determination of the amount adsorbed by the soil. Citrate, oxalate and humate were listed by Bradfield, Scarseth and Steele (1) as effectively reducing the retention of phosphate by clays, the order of effectiveness being the order in which they are named. Steele (19) attempted to compare the oxalate retained by clay with the amount of phosphate which the clay was prevented from fixing when suspended in a phosphate-oxalate solution in comparison with a pure phosphate solution. The results indicated considerably more oxalate retained than phosphorus released and he believed that oxidation of some of the oxalate by the soil was responsible for the discrepancies.

For the study of replacement of phosphate by oxalate, surface soil samples from cultivated fields in various locations in eastern Kansas were employed. In order to eliminate some of the sources of fixation of phosphorus, the organic matter and free iron oxides were removed from the samples by the method outlined by Truog, *et al.* (22). The samples were then subjected to the phosphorus fixation procedure described by Heck (8), that is, each soil sample was treated with a phosphate solution in a flask and the solution boiled vigorously until nearly dry, after which the evaporation was completed more slowly at a lower temperature. A 1-gram soil sample treated as just indicated was dispersed in a flask by shaking vigorously with 25 mls of distilled water, brought onto a filter paper in a small Büchner funnel and subjected to filtration with suction. The first portion of filtrate, if cloudy, was refiltered.

The soil sample was then leached on the funnel with distilled water until the leachate gave no test for phosphorus. The water leachate was then removed and the soil sample further leached with 50 mls of N/50 ammonium oxalate. This salt was chosen because its solution in water is practically neutral in reaction. The 50 mls were applied to the soil in 10 portions of 5 mls each. This was followed by further leaching of the soil sample with distilled water until the leachate gave no test for oxalate. The amount of oxalate retained by the soil was then determined by titrating the leachate with $KMnO_4$ and comparing the titration with that for an equivalent amount of the original oxalate solution. Phosphorus was determined colorimetrically in the oxalate leachate and also in the distilled water leachate.

Colorimetric determination of phosphorus by the improved Denigès method of Truog and Meyer (23) was attempted in the oxalate leachate after titration with N/50 $KMnO_4$. It was found that the determination could not be carried out satisfactorily under these

conditions. Neither could phosphorus be determined successfully in the presence of much unoxidized oxalate. However, when a portion of the oxalate filtrate was titrated with permanganate and the remaining portion likewise titrated to within about 0.3 ml of the end-point, the latter could then be used for the determination of phosphorus. The blue color of the phosphorus determination must be developed, however, at a pH value of 1.0 or below.

The soils, after treatment to remove free iron oxides, and after the phosphorus fixation treatment, had their base-adsorbing capacity partially satisfied by Na^+ and partially by K^+, since NaCl solutions were used in the washings of the first operation, and KH_2PO_4 solution was used in the phosphorus fixation treatment.

Samples of bentonite and of nontronite were included with the soil samples for comparison. These samples were prepared by saturating them with Na^+ by leaching with NaCl solution. After washing free of chlorides, the samples were digested over night at 80°–90° C with 1.5% Na_2CO_3 solution. The Na_2CO_3 solution was then filtered off and the samples washed free of carbonates. This treatment served to remove free silica and aluminum oxides from the samples.

The results of the replacement studies with several soils and with the nontronite and bentonite samples are given in Table 1.

TABLE 1.—*Phosphorus extracted from soils, first by water, than by ammonium oxalate, and oxalate retained.**

Sample description	Phosphorus leached out by water, p.p.m.	Additional phosphorus extracted by $(NH_4)_2C_2O_4$		Fixed phosphorus: not removed by		$(NH_4)_2C_2O_4$ retained by soil, M.E.†	pH of sample after phosphorus fixation
		P.p.m.	M.E.†	Water, p.p.m.	Water and $(NH_4)_2C_2O_4$, p.p.m.		
Bentonite	271	0.0	0.0	129	129	0.0	——
Nontronite	242	0.0	0.0	158	158	0.0	——
Soil No. 1	158	8.4	0.083	142	134	0.7	5.06
Soil No. 2	148	6.0	0.06	152	146	1.4	5.34
Soil No. 3	140	7.2	0.07	160	153	0.0	5.89
Soil No. 4	147	6.0	0.06	153	147	1.4	5.42
Soil No. 5	168	7.2	0.07	132	125	0.7	5.00
Soil No. 6	176	7.8	0.075	124	116	1.2	6.09
Soil No. 7	152	7.2	0.07	148	141	0.8	5.63
Soil No. 8	168	2.4	0.023	132	130	0.8	6.20
Soil No. 9	192	5.8	0.056	108	102	1.2	6.13
Soil No. 10	184	3.6	0.035	116	112	0.0	6.13

*The free R_2O_3 of the soils had been removed, followed by addition of 400 p.p.m. of P in solution as KH_2PO_4, and evaporation.

†Milligram equivalents per 100 grams of air-dry sample.

The data indicate no equivalent replacement of phosphate by oxalate. The results for the soil samples generally indicate more oxalate retained than phosphorus released but there are two exceptions. From approximately one-third to one-half of the phosphorus used in the fixation treatment was recovered when the soil samples

were leached with water. Very little of the remaining one-half to two-thirds of the added phosphorus was extracted by leaching the soil samples with the oxalate. Hence, it would not appear that more than an extremely small portion of the phosphorus with which the samples were treated was fixed in a replaceable form, at least in so far as replacement by the oxalate ion is concerned.

In bentonite and nontronite, no phosphorus was replaced and no oxalate was retained by the sample. It will be noted that about two-thirds of the added phosphorus was extracted in the water leachings. Although the pH values of these samples after phosphorus fixation were not determined, it is probable they approximated the values for the soil samples.

In some additional work with bentonite and nontronite, it was found that samples similarly treated with phosphate yielded 355 p.p.m. and 327 p.p.m. of phosphorus, respectively, when extracted by buffered 0.002 N H_2SO_4. Thus, the buffered H_2SO_4 removed 84 p.p.m. and 85 p.p.m., respectively, more than the oxalate, and 45 p.p.m. and 73 p.p.m., respectively, were fixed in such form as not to be extracted, even by the buffered acid.

It is of interest to note that the bentonite and nontronite each fixed considerably less phosphorus in a form not soluble in water than did the soil samples. This suggests the presence of some other products of weathering in the soil which fix phosphorus besides base exchange material and free iron oxides.

EFFECT OF REMOVAL OF FREE OXIDES OF FE AND AL ON PHOSPHORUS FIXATION

It appeared desirable to determine the effect of the removal of the free oxides of iron and aluminum on phosphorus fixing capacity for a group of soils representative of the types used in the various experiments reported in this paper.

In the various papers dealing with phosphorus adsorption the influence of the pH value at which fixation occurs is stressed. It appears that the pH range 5.0 to 6.0 has been found to be a range in which such fixation is said to occur. Such being the case, soils were chosen for this work whose pH values, before treatment, fell in the range 5.0 to 6.0.

Because of the difficulty of controlling the pH value of the system in the fixation procedure of Heck (8), in all succeeding experiments the soil samples were treated with a H_3PO_4 solution so adjusted with NaOH as to have a pH value in the range 5 to 6 after being shaken for 30 minutes with the soil sample. Less phosphorus is fixed by soil samples thus treated than with the boiling and evaporation of the Heck procedure. Four phosphate solutions were prepared, containing 19, 38, 57, and 95 p.p.m. of phosphorus, respectively. For each soil sample, a phosphate solution was chosen in accordance with the fixing capacity of the soil, a solution of high concentration being used for a soil with high fixing capacity and vice versa. Ten grams of soil were shaken with 50 mls of the phosphate solution on a mechanical shaker after which the suspensions were filtered, the phosphorus in the fil-

trate determined, and the phosphorus fixed calculated as the difference between that of the original solution and that of the filtrate.

Soil samples so selected representing the surface 7 inches of soil of cultivated fields, were subjected to removal of free iron oxides. Phosphorus fixation by these samples and by a duplicate set of samples from which the oxides had not been removed was then determined. The results are presented in Table 2.

TABLE 2.—*Phosphorus fixation in pH range 5.0 to 6.0 by soils before and after removal of free oxides of iron and aluminum.*

Soil type	Phosphorus fixation by original soil, p.p.m.	Phosphorus fixation after removal of free oxides, p.p.m.	Decrease of phosphorus fixation due to removal of free oxides	
			P.p.m.	%
Shelby silt loam	117.5	52.5	65.0	55.3
Lancaster loam	52.4	9.9	42.5	81.1
Idana silt loam	137.5	110.0	27.5	20.0
Lancaster silt loam	52.4	7.4	45.0	85.8
Gerald silty clay loam	122.5	22.5	100.0	81.6
Summit silty clay loam	59.9	27.4	32.5	54.4
Albion loam	44.9	2.5	42.4	94.4
Marshall silt loam	127.4	87.4	40.0	31.4
Labette silt loam	178.6	48.6	130.0	72.7
Wabash silt loam	147.7	102.4	45.3	30.6

The 10 soils listed varied rather widely in the percentage decrease in phosphorus fixation, the range being 20% to 94%. Only 3 of the 10 showed less than 50% decreases and 5 showed decreases of more than 70%. The data must not be taken too literally, however. Organic matter was removed by oxidation with H_2O_2 as the first step in the iron removal procedure and the phosphorus thus liberated was undoubtedly partially fixed by the mineral particles. The effect of this would be to decrease further fixation by the soil sample. On the other hand, the phosphorus extracted in the iron removal treatment was not determined, and this might tend to increase the fixation capacity as compared to the original soil. How these two effects compare in magnitude is not known. It can be said, however, that while other forms of fixation account for a portion of the phosphorus-fixing capacity of these soils, fixation by Fe and Al oxides apparently accounts for a large part of the fixing capacity, even in the pH range 5.0 to 6.0.

EFFECT OF DILUTE ACID EXTRACTION OF THE SOIL ON PHOSPHORUS-FIXING CAPACITY

Romine and Metzger (15) recently presented results indicating that extraction of a soil with buffered 0.002 N H_2SO_4 solution reduced its phosphorus fixing capacity. Fixation in the experiments reported in that paper was not studied under controlled pH conditions.

Two objectives were set up for additional work on the effect of dilute acid extraction on phosphorus-fixing capacity of the soil.

First, it seemed desirable to determine whether such extraction results in a disruption of the crystal structure of the particles which might account for the decrease in phosphorus fixing capacity. Second, it was desired to determine the effect of extraction on fixing capacity under conditions such that fixation should take place in the pH range 5.0 to 6.0, both before and after the extraction with the buffered acid. For this purpose soil samples were selected whose initial pH values fell in the range 5.0 to 6.0.

In order to determine whether or not extraction disrupts the crystal structure of the exchange particles, base exchange capacity was determined before and after extraction with buffered 0.002 N H_2SO_4. It was assumed that any appreciable change in crystal structure should manifest itself in a change of base exchange capacity. The results of this study with 12 samples from virgin soil profiles indicated that if change of base exchange capacity can be accepted as a criterion of crystal structure disruption, then it must be concluded that crystal structure was practically unaffected by extraction of the soil with the dilute acid. Since this has been demonstrated with other dilute acid extractants the data are not presented here.

In determining reduction of phosphorus fixing capacity resulting from extraction of the soil by dilute acid, the samples were shaken one-half hour with the extracting solution, centrifuged, the extract poured off and the sample then shaken one-half hour with a H_3PO_4 solution of appropriate concentration as explained on a preceeding page. Fixing capacity was also determined for the original soil. The results are given in Table 3. In this table the so-called "apparent fixing capacity" is a strictly arbitrary value and is obtained by adding the available phosphorus (that extracted by buffered 0.002 N H_2SO_4) to the phosphorus fixed by the original, or unextracted, soil. The soil samples were all taken from virgin soil profiles except the Nuckolls silt loam which came from an eroded, cultivated field.

The data of Table 3 indicate significant, and often large, reductions in phosphorus fixation resulting from the extraction of the soil with dilute acid. On the basis of the amount of phosphorus fixed by the original soil, the reductions ranged from about 12% to 75%. On the basis of "apparent fixing capacity" the range was approximately 13% to 78%. The greatest percentage reductions occurred with samples from the A horizons, generally, while the smallest reductions occurred with C horizon samples. This again indicates the presence of products of soil weathering in surface soils which influence phosphorus fixation markedly. The results of this experiment indicate that the order of magnitude of the reductions in fixation due to dilute acid extraction is not likely to be greatly different when fixation takes place in the pH range 5.0 to 6.0 than when this range is considerably lower, as was probably the case in the work reported by Romine and Metzger (15).

INFLUENCE OF THE NATURE OF THE EXCHANGEABLE CATIONS ON PHOSPHORUS FIXATION

Phosphorus fixing capacity of soil is somewhat influenced by the nature of the exchangeable cations as shown by Perkins, King and

TABLE 3.—*Effect of extraction of the soil with buffered 0.002 N H_2SO_4 on phosphorus fixation in the pH range 5.0 to 6.0.*

Soil type, horizon, and depth, inches	Phosphorus fixed by original soil, p.p.m.	Available phosphorus by the Truog method, p.p.m.	"Apparent fixing capacity", p.p.m.	Phosphorus fixed after extraction, p.p.m.	Reduction from original fixing capacity		Reduction from "apparent fixing capacity"	
					P.p.m.	%	P.p.m.	%
Cherokee silt loam A_0, 0–4	36.2	25.6	61.8	17.3	18.9	52.2	44.5	72.0
Cherokee silt loam A_1, 4–12	60.0	8.0	68.0	14.8	45.2	75.3	53.2	78.2
Cherokee silt loam B_1, 20–23	263.3	6.0	269.3	173.6	89.7	34.1	95.7	35.5
Cherokee silt loam B_2, 23–28	258.9	4.0	262.9	183.6	75.3	29.1	79.3	30.2
Nuckolls very fine sandy loam A_1, 3–9	102.5	22.4	124.9	37.4	65.1	63.5	87.5	70.0
Nuckolls very fine sandy loam A_2, 9–17	206.4	12.0	218.4	108.6	97.8	47.3	109.8	50.3
Nuckolls very fine sandy loam B, 17–27	213.9	10.0	223.9	113.6	100.3	46.9	110.3	49.3
Idana silt loam A_1, 5–15	80.0	16.0	96.0	37.4	42.6	53.2	58.6	61.0
Idana silt loam A_2, 15–19	107.5	19.2	126.5	62.4	45.1	41.9	64.3	50.8
Nuckolls silt loam A, 0–6	115.0	10.8	125.8	62.4	52.6	45.7	63.4	50.4
Nuckolls silt loam B, 6–16	216.4	9.6	226.0	143.6	72.8	33.6	82.4	36.5
Neosho silt loam A_0, 0–2	30.0	18.4	48.4	17.3	12.7	42.3	31.1	64.2
Neosho silt loam A_1, 2–7	36.2	6.0	42.2	22.3	13.9	38.4	19.9	47.1
Neosho silt loam A_2, 7–14	77.5	6.8	84.3	60.0	17.5	22.6	24.3	28.8
Neosho silt loam B, 14+	236.4	11.2	247.6	148.6	87.8	37.1	99.0	40.0
Labette silt loam A_0, 0–2	87.5	27.2	114.7	57.4	30.1	34.4	57.3	49.9
Labette silt loam A_1, 2–8	117.5	28.0	145.5	72.4	45.1	38.4	73.1	50.2
Labette silt loam A_2, 8–16	135.0	22.4	157.4	92.4	42.6	31.5	65.0	48.1
Labette silt loam B_1, 16–22	226.4	20.8	247.2	183.6	42.8	18.9	43.6	17.6
Labette silt loam B_2, 22–28	253.9	7.2	261.1	213.6	40.3	15.9	47.5	18.2
Labette silt loam C, 28+	411.5	6.4	417.9	361.0	50.5	12.3	56.9	13.6
Summit silt loam A_1, 0–7	66.2	12.0	78.2	34.8	31.4	47.4	43.4	55.5
Summit silt loam A_2, 7–9	140.0	6.0	146.0	97.4	42.6	30.4	48.6	33.3
Bates silt loam A_1, 0–6	73.7	8.4	82.1	34.8	38.9	52.8	47.3	57.6
Bates silt loam A_2, 6–8	140.0	5.2	145.2	97.4	42.6	30.4	47.8	32.9
Bates silt loam C, 29+	425.3	3.2	428.5	366.0	59.3	13.9	62.5	14.6

Benne (12), and others. It was therefore thought possible that replacement by the monovalent cations, H^+ and NH_4^+, in the extracting solution, of the divalent cations in the exchange material might account for much of the reduction in fixing capacity.

The soils used in obtaining the data in Table 3 had their base exchange capacities satisfied by calcium to the extent of at least 40% to 65% and exchangeable potassium is known to be relatively abundant in these soils. Accordingly, a group of samples from these same soils were leached with KCl solution, and another group was leached with $MgCl_2$ solution until the leachates gave no test for calcium. They were then further leached with 80% alcohol until the leachates gave no test for chlorides. The samples were then air-dried and phosphorus fixation determined, again adjusting the pH value of the phosphorus solution so that the suspension of soil in the phosphorus solution had a pH value in the range 5.0 to 6.0. The values thus obtained in comparison with the values for the original soil are presented in Table 4.

The replacement of the naturally occurring cations by K, in one instance, and Mg, in another, produced some surprising results. It was thought that probably replacement by K would lower the fixing capacity of the soil samples. This proved to be true for the upper part of nearly every profile, but when the lower part of the A horizon or the upper part of the B horizon was reached the effect was reversed. The writer has no adequate explanation for the increased fixation in the lower profile samples, unless it could be that the treatment with the potassium salt served to activate some of the iron and aluminum or other agents of fixation in these lower horizons. It will be recalled that treatment with the buffered acid reduced fixation in all horizons. Substitution of Mg increased phosphorus fixation with most samples. It did not do so uniformly, however, and the exceptions are A horizon samples, at or near the surface. The Nuckolls silt loam samples as explained previously were taken from an eroded, cultivated field, hence, the A horizon of this soil corresponded to the lower part of the A horizon of a virgin profile and showed increased fixation by the surface layer of soil.

The decrease of phosphorus fixation in the surface horizons resulting from the substitution of either K or Mg may be associated with the very high organic matter content of such samples. Doughty (4) has shown that soil organic matter has a low phosphorus fixing capacity and it is therefore difficult from this standpoint to see why the substitution of Mg, particularly, should lower the fixing capacity of such horizons. Decrease in fixation due to substitution of either K or Mg for Ca may be explained, however, on the basis of the greater solubility of the phosphorus compounds of K and Mg than those of Ca. The increase of fixation in lower horizons admits of no such simple explanation. It is interesting to note that when K markedly increased fixation, Mg did likewise. Also, the largest increases in fixation due to K and Mg occurred with the soil samples having the largest fixing capacities.

The divergent effects produced by substitution of these ions, particularly K, in the various horizons indicate that factors other than

adsorption must account for at least a very large part of the total fixing capacity of the soil. This is in agreement with the indications obtained from the results of the other experiments reported in this paper.

DISCUSSION

deVries and Hetterschij (24) have shown for a number of soils that there "was some parallelism" between the amounts of phosphorus extracted by lactic and citric acid solutions of different strengths and the combined quantities of Fe and Al removed. Romine and Metzger (15) presented data indicating a relationship between the reduction of the phosphorus fixing capacity of some Kansas soils due to extraction with dilute acid, and the quantity of R_2O_3 removed by the acid extraction. The correlation coefficient obtained from these data was $r = .497$. (Significant correlation coefficients at the 5% and 1% levels were .312 and .405, respectively). In unpublished studies by the author a negative correlation between available phosphorus of unfertilized soil as determined by the Truog method and increase in wheat yield due to phosphorus fertilization was established and the coefficient was $r = -.617$. (Significant correlation coefficients at the 5% and 1% levels were $-.482$ and $-.606$, respectively). These studies involved, along with others, the soils listed in Table 2. In view of these two correlations, and since the phosphorus fixing capacity is lowered by the same extraction which removes the available phosphorus, it seems possible that wheat grown on these soils, unless fertilized, is dependent to a large extent upon phosphorus combined with easily extractable sesquioxides.

One of the anions which has been proposed as being capable of replacement by phosphate, and which in turn may liberate phosphorus by replacement, is silicate. This relationship has been used to explain the oft-observed favorable influence of sodium silicate applications on crops grown on phosphorus deficient soils. The evidence thus obtained that phosphate is adsorbed and may be replaced by silicate is not entirely convincing. For example, in the results reported by Toth (21) the effects of calcium and magnesium silicates on the growth and phosphorus absorption of various crops showed fairly similar results when rock phosphate was the source of phosphorus as when phosphorus was supplied as superphosphate. Since phosphorus in rock phosphate is relatively only very slightly fixed by the soil while the phosphorus in superphosphate is strongly fixed, the replacement of phosphate by silicate may not be the correct explanation of the beneficial effect of silicates in these experiments. Gile and Smith (7) have shown that silica gel shaken with rock phosphate in water suspension produced a marked increase in water soluble phosphorus. Also Gaarder (6) showed that silica gel increased the amount of phosphorus in solution in the presence of Al, Ca and other elements which form relatively stable compounds with phosphorus. Perhaps, therefore, additions of silicate salts to the soil may bring about increased solubility of native soil phosphorus without a replacement of adsorbed phosphate by the silicate anion.

Ford (5) demonstrated by X-ray methods that when phosphates were fixed by Goethite and other minerals a new crystal structure

Benne (12), and others. It was therefore thought possible that replacement by the monovalent cations, H^+ and NH_4^+, in the extracting solution, of the divalent cations in the exchange material might account for much of the reduction in fixing capacity.

The soils used in obtaining the data in Table 3 had their base exchange capacities satisfied by calcium to the extent of at least 40% to 65% and exchangeable potassium is known to be relatively abundant in these soils. Accordingly, a group of samples from these same soils were leached with KCl solution, and another group was leached with $MgCl_2$ solution until the leachates gave no test for calcium. They were then further leached with 80% alcohol until the leachates gave no test for chlorides. The samples were then air-dried and phosphorus fixation determined, again adjusting the pH value of the phosphorus solution so that the suspension of soil in the phosphorus solution had a pH value in the range 5.0 to 6.0. The values thus obtained in comparison with the values for the original soil are presented in Table 4.

The replacement of the naturally occurring cations by K, in one instance, and Mg, in another, produced some surprising results. It was thought that probably replacement by K would lower the fixing capacity of the soil samples. This proved to be true for the upper part of nearly every profile, but when the lower part of the A horizon or the upper part of the B horizon was reached the effect was reversed. The writer has no adequate explanation for the increased fixation in the lower profile samples, unless it could be that the treatment with the potassium salt served to activate some of the iron and aluminum or other agents of fixation in these lower horizons. It will be recalled that treatment with the buffered acid reduced fixation in all horizons. Substitution of Mg increased phosphorus fixation with most samples. It did not do so uniformly, however, and the exceptions are A horizon samples, at or near the surface. The Nuckolls silt loam samples as explained previously were taken from an eroded, cultivated field, hence, the A horizon of this soil corresponded to the lower part of the A horizon of a virgin profile and showed increased fixation by the surface layer of soil.

The decrease of phosphorus fixation in the surface horizons resulting from the substitution of either K or Mg may be associated with the very high organic matter content of such samples. Doughty (4) has shown that soil organic matter has a low phosphorus fixing capacity and it is therefore difficult from this standpoint to see why the substitution of Mg, particularly, should lower the fixing capacity of such horizons. Decrease in fixation due to substitution of either K or Mg for Ca may be explained, however, on the basis of the greater solubility of the phosphorus compounds of K and Mg than those of Ca. The increase of fixation in lower horizons admits of no such simple explanation. It is interesting to note that when K markedly increased fixation, Mg did likewise. Also, the largest increases in fixation due to K and Mg occurred with the soil samples having the largest fixing capacities.

The divergent effects produced by substitution of these ions, particularly K, in the various horizons indicate that factors other than

adsorption must account for at least a very large part of the total fixing capacity of the soil. This is in agreement with the indications obtained from the results of the other experiments reported in this paper.

DISCUSSION

deVries and Hetterschij (24) have shown for a number of soils that there "was some parallelism" between the amounts of phosphorus extracted by lactic and citric acid solutions of different strengths and the combined quantities of Fe and Al removed. Romine and Metzger (15) presented data indicating a relationship between the reduction of the phosphorus fixing capacity of some Kansas soils due to extraction with dilute acid, and the quantity of R_2O_3 removed by the acid extraction. The correlation coefficient obtained from these data was $r = .497$. (Significant correlation coefficients at the 5% and 1% levels were .312 and .405, respectively). In unpublished studies by the author a negative correlation between available phosphorus of unfertilized soil as determined by the Truog method and increase in wheat yield due to phosphorus fertilization was established and the coefficient was $r = -.617$. (Significant correlation coefficients at the 5% and 1% levels were $-.482$ and $-.606$, respectively). These studies involved, along with others, the soils listed in Table 2. In view of these two correlations, and since the phosphorus fixing capacity is lowered by the same extraction which removes the available phosphorus, it seems possible that wheat grown on these soils, unless fertilized, is dependent to a large extent upon phosphorus combined with easily extractable sesquioxides.

One of the anions which has been proposed as being capable of replacement by phosphate, and which in turn may liberate phosphorus by replacement, is silicate. This relationship has been used to explain the oft-observed favorable influence of sodium silicate applications on crops grown on phosphorus deficient soils. The evidence thus obtained that phosphate is adsorbed and may be replaced by silicate is not entirely convincing. For example, in the results reported by Toth (21) the effects of calcium and magnesium silicates on the growth and phosphorus absorption of various crops showed fairly similar results when rock phosphate was the source of phosphorus as when phosphorus was supplied as superphosphate. Since phosphorus in rock phosphate is relatively only very slightly fixed by the soil while the phosphorus in superphosphate is strongly fixed, the replacement of phosphate by silicate may not be the correct explanation of the beneficial effect of silicates in these experiments. Gile and Smith (7) have shown that silica gel shaken with rock phosphate in water suspension produced a marked increase in water soluble phosphorus. Also Gaarder (6) showed that silica gel increased the amount of phosphorus in solution in the presence of Al, Ca and other elements which form relatively stable compounds with phosphorus. Perhaps, therefore, additions of silicate salts to the soil may bring about increased solubility of native soil phosphorus without a replacement of adsorbed phosphate by the silicate anion.

Ford (5) demonstrated by X-ray methods that when phosphates were fixed by Goethite and other minerals a new crystal structure

TABLE 4.—*Effect of the replacement of the naturally occurring exchangeable cations by K^+ and Mg^{++} on the fixation of phosphorus in the pH range 5.0 to 6.0.*

Soil type, horizon, and depth, inches	Phosphorus fixed by original soil, p.p.m.	Phosphorus fixed by K-soil, p.p.m.	Change in phosphorus fixation due to K, p.p.m.	Phosphorus fixed by Mg-soil, p.p.m.	Change in phosphorus fixation due to Mg, p.p.m.
Cherokee silt loam:					
A_0, 0–4	36	2	−34	12	−24
A_1, 4–12	60	26	−34	40	−20
B_1, 20–23	263	308	+45	352	+89
B_2, 23–28	259	324	+65	368	+109
Nuckolls very fine sandy loam:					
A_1, 3–9	102	88	−14	136	+34
A_2, 9–17	206	188	−18	240	+34
B, 17–27	214	204	−10	272	+58
Idana silt loam:					
A_1, 5–15	80	80	0	116	+36
A_2, 15–19	107	124	+17	148	+41
Nuckolls silt loam:					
A, 0–6	115	136	+21	160	+45
B, 6–16	216	202	−14	308	+92
Neosho silt loam:					
A_0, 0–2	30	0	−30	8	−22
A_1, 2–7	36	14	−22	36	0
A_2, 7–14	77	104	+27	116	+39
B, 14+	236	308	+72	308	+72

Labette silt loam:					
A_0, 0–2	87	64	−23	100	+13
A_1, 2–8	117	104	−13	140	+23
A_2, 8–16	135	104	−31	156	+21
B_1, 16–22	226	260	+34	292	+66
C, 28+	411	605	+194	596	+185
Summit silt loam:					
A_1, 0–7	66	38	−28	64	−2
A_2, 7–9	140	148	+8	168	+28
Bates silt loam:					
A_1, 0–6	74	42	−32	64	−10
A_2, 6–8	140	164	+24	172	+32
C, 29+	425	557	+132	548	+123

was indicated. Stout (20) reported recently that kaolinite possesses much higher phosphorus fixing capacity than bentonite because of the larger quantities of hydroxol ions available for exchange in the former than in the latter. He was able to change the crystal structure of kaolinite by phosphating it, as indicated by X-ray studies, but reports that he restored the original structure by leaching the kaolinite with an alkaline solution (pH 9.0) and washing with dilute HCl (pH 3.0).

Dean (3) extracted Rothamsted soils with N/4 NaOH and followed this by extraction with N/2 H_2SO_4. He found that half or more of the total phosphorus was not removed by these treatments. This non-extracted portion was not increased by long-continued fertilizer applications. Hence, it appears that a goodly portion of the phosphorus in these soils was neither replaceable by OH^- ions nor extractable with dilute acid.

It is not the purpose of the author to attempt to prove or disprove the theory of phosphorus adsorption by clay particles. However, it appears evident from results presented here and cited from other sources that the phosphorus fixation problem is quite different where the unfractionated soil in its natural condition is dealt with than where one works with a purified clay fraction, or a still more homogenous clay mineral.

Davis (2) studied phosphorus fixation intensively and apparently concluded, at least tentatively, that in acid soils the fixation of phosphorus can be accounted for largely by absorption and that adsorption must play a minor role. It appears to be rather generally conceded that fixation in alkaline soils is largely accounted for by precipitation in combination with divalent bases.

SUMMARY

Phosphorus fixation has been studied with surface soil samples from cultivated fields and with samples from the various horizons of virgin soil profiles.

Samples from which the free oxides of iron and aluminum had been removed were treated with KH_2PO_4 solution and the water soluble phosphate leached out. The samples were then leached with ammonium oxalate solution in an attempt to demonstrate an equivalent replacement of phosphate by oxalate. Only very small amounts of phosphate could be removed by the oxalate and there were no indications of an equivalent replacement. Samples of bentonite and nontronite showed similar results.

Removal of free oxides of iron and aluminum reduced the fixing capacity (in the pH range 5.0 to 6.0) of 10 soil samples by amounts varying from 20% to 94%.

Extraction of soil samples with buffered 0.002 N H_2SO_4 reduced the fixing capacity of the soil (measured in the pH range 5.0 to 6.0) by from 12% to 78%. It was shown that this treatment scarcely altered the base exchange capacity of the samples and therefore it was assumed that the reduction of phosphorus fixing capacity could not be attributed to disruption of the crystal structure of the base exchange particles by the dilute acid treatment.

Replacement of the naturally occurring exchangeable cations (predominantly Ca^{++}) from the soil particles by K^+ lowered the phosphorus fixing capacity of most samples from the A horizons of virgin soils. Samples from the lower A horizons and the B and C horizons showed increased fixing capacity after such treatment. The same was true when Mg^{++} was substituted for the naturally occurring cations except that fewer samples showed reduced fixing capacity.

The effects of the various treatments on phosphorus fixing capacity suggest the presence and activity in unfractionated and unaltered soils of accumulated products of soil forming processes which play a dominant role in phosphorus fixation.

The conclusion is drawn that, for acid soils under field conditions absorption, or chemical precipitation, may account very largely for phosphorus fixation and that adsorption, a surface phenomenon, is probably of small practical significance.

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THE GROWTH HABITS AND CHEMICAL COMPOSITION OF BROMEGRASS, *BROMUS INERMIS* LEYSS, AS AFFECTED BY DIFFERENT ENVIRONMENTAL CONDITIONS[1]

JAMES M. WATKINS[2]

PIPER (6)[3] and other investigators have reported that bromegrass, *Bromus inermis* Leyss, if allowed to grow undisturbed for two or three years, becomes "sod-bound." A marked decrease in the percentage of fertile shoots produced is associated with this condition. This characteristic has been observed in other grasses and as yet no definite explanation has been offered. The investigations of Kraus and Kraybill (5) with the tomato, *Lycopersicon esculentum*, indicate that fruitfulness is associated with a balance between the nitrates and carbohydrates in the above-ground parts. In order to obtain information as to the relation of these constituents to the habits of growth of bromegrass, studies of two types were undertaken: First, the effects of nitrogen fertilizer, shade, shade combined with nitrogen fertilizer, and the associated growth of alfalfa with bromegrass upon its habits of growth and chemical composition; and second, the effects of length of day upon such qualities and characteristics of bromegrass.

EFFECT OF NITROGEN FERTILIZER, SHADE, SHADE COMBINED WITH NITROGEN FERTILIZER, AND MIXTURE WITH ALFALFA UPON THE GROWTH HABITS AND CHEMICAL COMPOSITION OF BROMEGRASS

PLAN OF EXPERIMENT

Bromegrass seed of a commercial strain from Saskatchewan was seeded on plots 10×10 feet on September 1, 1936, and on August 28, 1937. The plots were arranged in the following order: Nitrogen fertilized, check, mixture with alfalfa, and shaded. Since the alfalfa in the 1936 seeding failed to survive, a plot both shaded and fertilized with nitrogen was substituted.

Shading was provided by bleached sheeting over wooden frames constructed to allow 6 inches at the bottom and an opening on the north side for ventilation. The frames were placed on the plots of each seeding on March 24, 1938. The light intensity under the frames ranged from 300 to 800 foot candles as compared to normal sunlight of 4,000 to 10,500 foot candles on July 7, 1938.

Records were obtained on the date of appearance of leaves, increase in height of shoots, elongation of internodes, appearance of fertile and sterile[4] shoots, ap-

[1]Contribution from the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, cooperating with the Department of Agronomy, Ohio Experiment Station, Wooster, Ohio. A review of a thesis presented to the Department of Agronomy, Ohio State University, in partial fulfillment of the requirements for the doctor's degree. Received for publication April 20, 1940.

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[3]Figures in parenthesis refer to "Literature Cited", p. 537.

[4]Sterile shoot same as vegetative shoot (absence of inflorescence).

pearance and growth of rhizomes, and the yield of plant parts. The yields were determined from square-foot areas taken to a depth of 6 inches.

Duplicate determinations of total nitrogen, free reducing sugars, sucrose, and easily hydrolyzed carbohydrates were made in 50-gram samples of hay, stubble, and roots; and in 10-gram samples, of rhizomes from plots in the 1936 seeding.

Extraction of the samples.—The samples were extracted with 80% alcohol for 12 hours in large Soxhlet extractors.

Total nitrogen.—Determinations for nitrogen in the extract and dry residue were made by the official Kjeldahl method.

Free reducing sugars.—Fifty cc of alcohol extract were placed in a 100-cc volumetric flask and the alcohol driven off on the steam bath. The sample was cleared with lead acetate and potassium oxalate, then made up to volume and filtered. A 25-cc aliquot was used for the determination of free reducing sugars.

Total sugars.—Two drops of invertase (1% solution of Wallensteins' red label) were added to a 25-cc aliquot of the cleared extract and allowed to remain for 2 hours. After inversion, determinations were made for free reducing sugars. To determine the percentage *sucrose*, the percentage free reducing sugars was subtracted from the percentage total sugars.

Easily hydrolyzed carbohydrates.—A 2-gram sample of the dry residue was ground fine and hydrolyzed with 2.5% HCl for 2.5 hours in a receiving flask. The free reducing sugars were determined on a 10-cc aliquot of the filtrate.

GROWTH HABIT STUDY

The rate of appearance of leaves was changed very little by different environmental treatments. Nitrogen fertilizer increased the rate of appearance slightly over that of the check plot. Blackman and Templeman (1) obtained similar results on rate of leaf production in *Agrostis tenuis* and *Festuca rubra* as affected by nitrogen fertilizer. Shading of bromegrass plants reduced the rate of appearance of leaves in the fall, but had little effect in the spring and summer as compared with the check plants.

Rhizomes appeared in the first two weeks of May following the previous fall seeding. The number of rhizomes per plant appeared to be dependent in part upon the density of the stand. Very few rhizomes were observed in dense stands. Dexter (2) reported similar results on the number of quack grass rhizomes as affected by the density of stand.

Data on square-foot harvests from the two sets of plots at three different dates are presented in Tables 1 and 2. The nitrogen-fertilized plot produced the highest number of fertile shoots in all instances. Shading of the plants definitely decreased the number of fertile shoots produced. The percentage fertile shoots recorded on June 30, 1938, was 50 in the nitrogen-fertilized plot as compared to 35 in the check plot, 18 in the shaded nitrogen-fertilized plot, and 10 in the shaded plot.

The total number of shoots produced was greatest in the nitrogen-fertilized plot; however, the difference between the nitrogen-fertilized plot and check plot was slight in the 1936 seeding. Shading decreased the total number of shoots per unit area,

The number of rhizomes produced per square-foot area was greatest in the check plot. Both nitrogen fertilizer and shade tended to decrease the number of rhizomes produced.

The height of fertile shoots was increased by shade and nitrogen fertilizer. Shade seemed to be the most effective of the two treatments. The plants both shaded and fertilized with nitrogen fertilizer attained the greatest height at the time of maturity. The number of elongated internodes on fertile shoots was greatest on the shaded plants, and they were more uniform in length than on the unshaded plants.

TABLE 1.—*Shoots and rhizomes from square-foot areas in each plot.*

Treatment	Average number per square foot				Average height of fertile shoots, inches
	Fertile shoots	Sterile shoots	Total shoots	Rhizomes	
Two Square-foot Harvests per Plot, June 25, 1938, in 1937 Seeding					
Check plot.........	17.5	130.5	148.0	24.0	13.3
N-fertilized plot*...	54.5	127.5	182.0	22.5	35.6
Shaded plot........	0.0	103.5	103.5	7.0	——
Alfalfa-bromegrass plot............	10.0	122.0	132.0	8.0	28.1
Four Square-foot Harvests per Plot, July 5, 1938, in 1936 Seeding					
Check plot.........	25.5	110.0	135.0	57.5	28.2
N-fertilized plot*...	46.3	84.7	131.0	38.5	38.6
Shaded plot........	16.0	86.5	102.0	19.5	45.4
Shaded N-fertilized plot*...........	19.0	86.5	105.5	15.5	49.0
Four Square-foot Harvests per Plot, Aug. 2, 1938, in 1937 Seeding					
Check plot.........	7.0	139.0	146.0	29.5	24.5
N-fertilized plot*...	33.5	173.2	206.7	15.2	41.3
Shaded plot........	0.0	71.5	71.5.	7.2	——
Alfalfa-bromegrass plot............	8.2	103.5	111.7	10.2	37.2

*Ammonium sulfate at the rate of 150 pounds per acre was applied on March 24 and July 2, 1938. The 1937 seeding was fertilized at the same rate on September 20, 1937.

The yield of hay on the fertilized plot was about four times as great as the check plot in the 1937 seeding, as shown in Table 2. Shading of the plots decreased the amount of dry weight as compared with the check plots. The yield of alfalfa and bromegrass hay together approached the yield of hay obtained on the nitrogen-fertilized plot.

In all instances the check plot produced the greatest dry weight of bromegrass rhizomes. The production of bromegrass rhizomes was retarded by nitrogen fertilizer. This response to nitrogen fertilizer was observed by Willard and McClure (8) in Kentucky bluegrass. Dexter (2) obtained similar results with high nitrogen fertilization in the production of rhizomes in quack grass. Both shade and alfalfa mixture decreased the yield of bromegrass rhizomes.

TABLE 2.—*Yield in pounds dry weight per acre calculated from square-foot harvests made in 1938.*

Treatment	Yield in pounds per acre				
	Hay	Stubble	Roots	Rhizomes	Total
	June 25 Harvest, 1937 Seeding				
Check	1,300	1,550	1,370	80	4,300
N-fertilized*	5,890	2,590	1,540	50	10,070
Shaded	1,180	440	350	5	1,975
Alfalfa-bromegrass	1,100	750	760	20	2,630
alfalfa	4,080	710	1,100		5,890
Total alfalfa-grass mixture	5,180	1,460	1,860	20	8,520
	July 5 Harvest, 1936 Seeding				
Check	2,170	3,280	3,400	340	9,190
N-fertilized*	4,930	2,950	2,940	240	11,060
Shaded	2,580	1,290	1,580	70	5,520
Shaded N-fertilized*	2,970	1,850	1,410	70	6,300
	August 2 Harvest, 1937 Seeding				
Check	1,730	1,030	2,570	90	5,420
N-fertilized*	6,930	2,110	2,370	60	11,470
Shaded	1,460	360	280	15	2,115
Alfalfa-bromegrass	1,710	550	920	30	3,210
alfalfa	2,820	390	1,050		4,260
Total alfalfa-grass mixture	4,530	940	1,970	30	7,470

*Ammonium sulfate at the rate of 150 pounds per acre was applied on March 24 and July 2, 1938. The 1937 seeding was fertilized at the same rate on September 20, 1937.

The yield of roots appeared to be stimulated by nitrogen fertilizer in the early stages of growth. After the plants were well established, the nitrogen fertilizer tended to retard the growth of the roots as indicated by the data obtained on July 5 and on August 2. Since the samples were taken to a depth of only 6 inches, the data are not complete; however, examination of the soil to a depth of 12 inches indicated that a small percentage of the roots extended to a greater depth than 6 inches.

The nitrogen-fertilized plants produced the greatest total dry weight of plant parts. This was followed in succession by the check plot, shaded nitrogen-fertilized plot, and the shaded plot in the 1936 seeding. In the 1937 seeding, the bromegrass in the alfalfa mixture yielded more than the shaded plot.

CHEMICAL ANALYSES

The duplicate analyses of plant parts were in relatively close agreement. Analyses of plant parts harvested June 29–30, 1938, from the 1936 seeding, are presented in Table 3. The percentage free reducing sugars was approximately the same in the hay samples for each treatment. The stubble showed an increase in free reducing sugars in the nitrogen-fertilized plants over that of the check plants. This effect

was even more pronounced in the rhizomes. In the analysis of total plants, the nitrogen-fertilized plants contained the highest percentage of free reducing sugars.

The percentage sucrose present in the hay was highest in the two fertilized plots. The percentage in the underground parts appeared to be decreased by shading of the plants. Nitrogen fertilizer gave the highest percentage of sucrose in the total plant.

There was no definite trend shown in the percentage of easily hydrolyzed carbohydrates with different treatments. Total carbohydrates determined were higher in the unshaded plants than in the

TABLE 3.—*Chemical analyses of plant parts harvested June 29–30, 1938, from the 1936 seeding.*

Material	Treatment			
	Check %	N-fertilized %	Shaded %	Shaded N-fertilized %
Hay:				
Relative proportion of parts	23.6	44.5	46.8	47.2
Free reducing sugars	1.6	2.2	2.0	2.1
Sucrose	1.7	2.0	0.5	2.1
Easily hydrolyzed carbohydrates	26.2	29.1	24.3	22.5
Total carbohydrates determined	29.5	33.3	26.8	26.7
Total nitrogen	1.7	1.4	1.9	2.3
Stubble:				
Relative proportion of parts	35.7	26.7	23.4	29.3
Free reducing sugars	1.0	1.4	1.0	1.0
Sucrose	1.4	0.9	0.8	0.8
Easily hydrolyzed carbohydrates	31.4	31.3	27.2	26.8
Total carbohydrates determined	33.8	33.6	29.0	28.6
Total nitrogen	0.8	0.9	1.2	1.8
Roots:				
Relative proportion of parts	37.0	26.6	28.6	22.4
Free reducing sugars	0.8	0.7	0.5	0.4
Sucrose	1.2	1.2	0.5	0.5
Easily hydrolyzed carbohydrates	28.2	26.8	28.5	28.2
Total carbohydrates determined	30.2	28.7	29.5	29.1
Total nitrogen	0.9	1.0	1.0	1.8
Rhizomes:				
Relative proportion of parts	3.7	2.2	1.2	1.1
Free reducing sugars	2.0	3.1	1.3	1.6
Sucrose	2.0	2.3	0.1	1.3
Easily hydrolyzed carbohydrates	30.5	29.4	26.6	25.6
Total carbohydrates determined	34.5	34.8	28.0	28.5
Total nitrogen	1.0	1.2	1.7	2.6
Total plant:				
Relative proportion of parts	100.00	100.00	100.00	100.00
Free reducing sugars	1.17	1.67	1.22	1.39
Sucrose	1.37	1.55	0.50	1.31
Easily hydrolyzed carbohydrates	28.90	28.90	26.20	25.00
Total carbohydrates determined	31.44	32.12	27.92	27.70
Total nitrogen	1.04	1.13	1.52	2.03

shaded plants; however, there was little difference between the two shaded plots or between the two unshaded plots.

The percentage of nitrogen was highest in the shaded nitrogen-fertilized plot and lowest in the check plot. Little difference was shown in the percentage of nitrogen between the two shaded plots or between the two unshaded plots. The ratio of carbohydrates determined to total nitrogen in bromegrass—check plot, 28.2:1; nitrogen-fertilized plot, 27.5:1; shaded plot, 18.8:1; and shaded nitrogen-fertilized plot, 13.6:1—gives a more contrasting difference than a comparison of the percentage within the plant.

There appears to be little correlation between the chemical analyses and shoot growth. The total number of fertile shoots produced in the nitrogen-fertilized plot was about twice as great as in the check plot, and yet the analyses are similar and the ratios are approximately the same. If the yields of plant parts harvested on July 5, 1938, from the 1936 seeding, are used to determine the yield of carbohydrate fractions and total nitrogen per acre, a more definite relationship is shown. The amount of carbohydrate determined for the whole plant in the check plot was 2,890 pounds per acre as compared with 3,550 in the nitrogen-fertilized plot, 1,540 in the shaded plot, and 1,750 in the shaded nitrogen-fertilized plot. The amounts of nitrogen were about the same in the two unfertilized plots and the same in the two fertilized plots. With high amounts of nitrogen and normal light intensity, there is an increase in the production of shoots in number and dry weight. This is accompanied by a decrease in the number and weight of rhizomes which serve as a source of organic reserves for the stimulated top growth. With the added stimulus of nitrogen fertilizer, there is sufficient food material to cause the initiation and growth of more fertile shoots. Conversely, when the fertility level is low, the excess carbohydrates produced are stored or used in the production of more rhizomes. The hypothesis is suggested that, if the latter condition exists for a few years, a dense sod is formed and some type of special treatment is needed to stimulate the top growth.

Shading of the bromegrass plants had somewhat the same effect as the nitrogen fertilizer upon the general growth habit. The carbohydrate reserves in the rhizomes and the carbohydrates produced were used in the production of top growth. This resulted in a decrease in the number and weight of rhizomes.

These results suggest that under normal conditions of growth of bromegrass, there is a tendency toward excess storage in the underground parts. This condition may be altered by stimulating the top growth with nitrogen fertilizer in the spring. This effect tends to be carried over throughout the growing season.

EFFECT OF LENGTH OF DAY UPON GROWTH HABITS AND CHEMICAL COMPOSITION OF BROMEGRASS

PLAN OF EXPERIMENT

Three experiments were conducted with duplicate plots of bromegrass under three different lengths of day. The experiments extended from (a) May 17 to July 9, 1937, (b) September 20 to November 27, 1937, and (c) April 2 to July 28,

1938. Experiments (a) and (c) consisted of plants transplanted to rows one foot apart and spaced 6 inches apart in the rows. The plants in experiment (b) were grown from seed in rows 8 inches apart and thinned on September 20 to approximately 4 inches apart. The dark boxes and lights were used alike in all experiments.

One set of plots was covered each day from 4:30 p.m. to 8:00 a.m. with ventilated boxes, thus giving the plants 8.5 hours daily illumination. A second set of plots was grown under natural illumination. The third set of plots, located about 400 feet from the other plots, was artificially illuminated so that it received 18 hours daily illumination. At the surface of the soil the artificial illumination ranged from 65 to 80 foot candles throughout the plot area.

As far as possible in all three experiments, records were obtained on all plants as to the number of fertile shoots, number of sterile shoots, length of longest shoot, and number and length of rhizomes. Yields of plant parts were determined on 30 plants from each length of day in 1938. Analyses for carbohydrate fractions and nitrogen were made on samples of hay, stubble, roots, and rhizomes collected on July 28, 1938, from each length of day. The methods of analysis are described on page 528.

GROWTH OF SHOOTS AND RHIZOMES

Plants grown under short days produced a rosette type of growth and the shoots developed in a decumbent position. The plants grown under normal and long days developed in an upright position, the long-day plants attaining a greater height than the normal-day plants. Records obtained on the growth habits of shoots on these plants at the end of each experiment are presented in Table 4.

No differences in the number of fertile shoots per plant were obtained in the plots in 1937, since plants were transplanted in the spring after inflorescences were initiated. In 1938 the plants were

TABLE 4.—*Average number and length of shoots per plant as affected by different lengths of day.*

Date and length of day	Fertile shoots per plant, No.	Total shoots per plant, No.	Height of tallest sterile shoots per plant, in.*	Height of tallest fertile shoots per plant, in.
July 9, 1937:				
Short days, 8.5 hours	1.0	20.9	†	12.2
Normal days, 15.0 hours	1.0	17.0	†	20.3
Long days, 18.0 hours	0.8	10.9	†	25.8
November 24, 1937:				
Short days, 8.5 hours	None	7.6	5.3	
Normal days, 11.0 hours	None	7.1	5.1	
Long days, 18.0 hours	None	3.1	14.2	
July 28, 1938:				
Short days, 8.5 hours	1.2	24.7	7.4	15.3
Normal days, 15.0 hours	3.7	21.7	14.6	22.8
Long days, 18.0 hours	1.4	16.7	30.7	25.3

*Measurements made from base of shoot to uppermost ligule.
†Not determined.

transplanted early and the greatest number of fertile shoots developed under normal days. These data indicate that bromegrass would fall into the class of indeterminate plants described by Garner (4). None of the shoots on plants grown in the fall of 1937 showed initiation of inflorescences. If the plants had been subjected to different lengths of day throughout their early growth in fall and spring, the reaction might be somewhat different with respect to development of inflorescences.

The total number of shoots per plant became greater with a decrease in length of day. With an increase in length of day, the height of the shoots became greater. When plants were grown under long days for a period after maturity, the sterile shoots attained a greater height than the fertile shoots.

Data on the growth of rhizomes on plants from the three dates of experiments are shown in Table 5. The data indicate that length of day has a definite effect on the production of rhizomes, the greatest number being produced under normal days in the spring and summer.

TABLE 5.—*Average number and length of rhizomes as affected by different lengths of day.*

Date and length of day	Primary rhizomes per plant, No.	Branch rhizomes per plant, No.	Total rhizomes per plant, No.	Length of longest rhizomes per plant, in.
July 9, 1937:				
Short day, 8.5 hours	6.1	1.9	8.0	2.7
Normal day, 15.0 hours	11.7	4.6	16.3	3.8
Long day, 18.0 hours	8.5	7.0	15.5	4.0
November 24, 1937:				
Short day, 8.5 hours	None	None	0	0
Normal day, 11.0 hours	None	None	0	0
Long day, 18.0 hours	2.2	None	2.2	2.3
July 28, 1938:				
Short day, 8.5 hours	3.4	0.6	4.0	*
Normal day, 15.0 hours	9.7	2.9	12.6	*
Long day, 18.0 hours	6.2	2.8	9.0	*

*Not determined.

The rhizomes on plants grown under long days attained a greater length and appeared to be larger in diameter than those on plants from the other two lengths of day. Conversely, it was observed that the plants grown under short days produced more above-ground shoots from rhizomes than the normal or long-day plants.

The indications from all experiments seem to be conclusive that length of day is an important factor in the production of rhizomes. Evans and Watkins (3) found that rhizome production on bluegrass was strongly affected by length of day. The greatest number developed on *Poa compressa* in the early spring and late fall, or under short days; and on *Poa pratensis* in the late spring and early summer, or under relatively long days.

The yield per acre of plant parts of bromegrass was determined on 30 plants from each length of day in 1938. The data are shown in Table 6. Long days tended to increase the proportion of hay and rhizomes. The yield of stubble and roots under long days was not appreciably increased over that of normal-day plants. In similar experiments with *Dactylis glomerata* and *Phleum pratense*, Tinker (7) obtained less dry weight of tops of both grasses under short days than under long days.

TABLE 6.—*Yield per acre of plant parts on July 28, 1938, as affected by length of day.*

Material	Yield per acre, lbs.		
	Short day	Normal day	Long day
Hay	1,780	2,520	4,780
Stubble	870	1,380	1,310
Roots	500	910	910
Rhizomes	70	230	400
Total	3,220	5,040	7,400

CHEMICAL[1] ANALYSES

Analyses of plant parts harvested on July 28, 1938, are given in Table 7. The percentage of free reducing sugars increased in all plant parts with an increase in length of day. This is shown rather definitely in the analysis of the total plant. The percentages of sucrose are erratic, showing no definite trend with change in length of day. Long days tended to increase the percentage of easily hydrolyzed carbohydrates in the hay and stubble, with a corresponding decrease in roots and rhizomes. The total carbohydrates determined in hay, stubble, and the total plant were highest under long days; the underground parts showed little variation with change in length of day.

The total percentage nitrogen showed a decline with increase in length of day in all plant parts with the exception of roots. It is apparent that with a decided change in total dry weight, the percentage of nitrogen would vary accordingly. The ratio of carbohydrates to total nitrogen—short day, 6.3:1; normal day, 12.5:1; and long day, 15.4:1—is not in accord with that obtained in the first part of this study. The ratio for the normal-day plants is much lower than that for the check plants. The probable explanation for this difference is found in the arrangement of plants, the length-of-day plants being grown individually without competition.

The actual amounts of nitrogen per acre as determined from the yields in Table 6 are relatively the same—short day, 70 pounds; normal day, 60 pounds; and long day, 80 pounds. The total carbohydrates determined were—short day, 410 pounds; normal day, 740 pounds; and long day, 1,380 pounds. No definite correlations are apparent between these data and the growth habits observed. It appears, however, that length of day is important for the maximum

TABLE 7.—*Chemical analyses of plant parts harvested July 28, 1938, from length-of-day plots.*

Material	Length of day, %		
	Short day, 8.5 hours	Normal day, 15 hours	Long day, 18 hours
Hay:			
Relative proportion of parts	55.1	49.6	64.5
Free reducing sugars	1.0	1.4	2.7
Sucrose	1.9	1.2	1.3
Easily hydrolized carbohydrates	15.9	22.8	23.8
Total carbohydrates determined	18.8	25.4	27.8
Total nitrogen	5.2	3.3	2.4
Stubble:			
Relative proportion of parts	26.5	27.2	18.0
Free reducing sugars	1.8	1.6	2.8
Sucrose	0.9	1.6	1.4
Easily hydrolyzed carbohydrates	25.5	29.4	28.4
Total carbohydrates determined	28.2	32.6	32.6
Total nitrogen	2.4	1.4	0.9
Roots			
Relative proportion of parts	16.1	18.1	12.1
Free reducing sugars	0.8	0.8	1.5
Sucrose	0.4	*	1.6
Easily hydrolyzed carbohydrates	29.2	27.9	26.9
Total carbohydrates determined	30.4	28.7	30.0
Total nitrogen	1.1	1.1	1.1
Rhizomes:			
Relative proportion of parts	2.3	5.1	5.4
Free reducing sugars	1.8	4.0	4.5
Sucrose	1.0	1.2	2.2
Easily hydrolyzed carbohydrates	34.8	34.1	30.7
Total carbohydrates determined	37.6	39.3	37.4
Total nitrogen	1.1	1.5	1.4
Total plant:			
Relative proportion of parts	100.0	100.0	100.0
Free reducing sugars	1.1	1.4	2.7
Sucrose	1.3	1.1	1.3
Easily hydrolyzed carbohydrates	21.0	26.0	25.4
Total carbohydrates determined	23.4	28.5	29.4
Total nitrogen	3.7	2.3	1.8

*Not sufficient extract for analysis.

production of fertile shoots and rhizomes. After the required length of day is exceeded, the additional carbohydrates produced are used in the growth of the vegetative parts in size and length.

SUMMARY

Bromegrass, *Bromus inermis* Leyss, was studied with respect to (a) the effects of nitrogen fertilizer, shade, shade combined with nitrogen fertilizer, and mixture with alfalfa upon the growth habits and chemical composition; and (b) the effects of length of day upon

such qualities and characteristics. The results may be summarized as follows:

Fertilization with nitrogen increased the rate of leaf production, height and total number of shoots, number of fertile shoots, and dry weight of tops, but decreased the number of rhizomes and weight of the underground parts.

Shade decreased the number of shoots, number of rhizomes, number of fertile shoots, and dry weight of all plant parts. It increased the number of elongated internodes and the height of the plant. The internodes were more uniform in length than those on shoots from other plots.

The associated growth of alfalfa with bromegrass decreased the number of shoots, number of rhizomes, and dry weight of the plants of bromegrass.

The nitrogen-fertilized plants and check plants at bloom stage were low in percentage of nitrogen and high in percentage of carbohydrates; however, the absolute amounts of both were highest in the nitrogen-fertilized plants. The shaded plants were high in percentage of nitrogen and low in percentage of carbohydrates as compared to the check plants.

Plants grown under short days (8.5 hours) produced a rosette type of growth and the shoots developed in a decumbent position. The plants grown under normal days (15 hours) and long days (18 hours) developed in an upright position, the long-day plants attaining a greater height than the normal-day plants.

The total number of shoots per plant was greatest under short days and least under long days. More fertile shoots were produced on the normal-day plants than under either the short or long day treatments.

The maximum number of rhizomes was produced under the normal day length in late spring or summer. The rhizomes attained the greatest size and length under the long days.

The dry weight of plant parts increased as the number of light hours per day was lengthened.

Both the percentage and absolute amounts of carbohydrates were highest in the long-day plants. The short-day plants contained the highest percentage of nitrogen; however, the absolute amounts were about the same under each length of day.

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LINKAGE BETWEEN THE MARTIN AND TURKEY FACTORS FOR RESISTANCE TO BUNT, *TILLETIA TRITICI*, IN WHEAT[1]

FRED N. BRIGGS[2]

As a result of investigations of the genetics of resistance to bunt, *Tilletia tritici*, in wheat, the author has found (2)[3] three major genetic factors for resistance to this disease which have been designated as the Martin (*M*), Hussar (*H*), and Turkey (*T*) factors, respectively. The Martin factor has been found alone in White Odessa, Banner Berkeley, Odessa, and Sherman wheats in addition to the Martin variety which is used as a tester for this factor (3). The Hussar factor has been found only in Hussar wheat, along with the Martin factor, but has been isolated in Selection 1403, which is used as a tester for this factor (1). The Turkey factor has been found alone in Turkey 3055, Turkey 1558, Oro, Turkey 1558B, and Turkey 2578. Turkey 3055 has been used as a tester for this factor (4).

In the investigation of resistance to bunt in a resistant variety the usual procedure has been to cross such a variety with a susceptible one in order to determine the number of factors present. At the same time, crosses have been made with the tester varieties to determine the identity of such factors, the absence of susceptible progeny in F_3 indicating the presence of the same factor in both parents. Crosses with tester varieties which show susceptible progeny usually have been examined to see if the number of susceptibles conforms to the number expected on the basis of independent assortment of the factors involved. The data from the individual crosses between varieties containing the Martin and Turkey factors appeared to conform to the 15:1 ratio which would be expected on the basis of two independent factors.

Recently, the author had occasion to re-examine the data from all the crosses involving the Martin and Turkey factors. The F_3 data from these crosses are shown in Table 1.

Resistant and segregating rows cannot be accurately separated, but susceptible rows can be identified with a good deal of certainty. With the exception of Martin×Turkey 1558 the observed numbers are in satisfactory agreement with the expected numbers calculated on the basis of the 15:1 ratio. The cross between Martin and Turkey 1558 had a P value of 0.03. However, it will be noted that all the deviations are in the same direction. The total X^2 value for all six crosses is 16.535 which give a P value less than 0.01. When the data from all the crosses are considered together there are only 25 susceptible rows where 53.4 are expected out of a total of 854. This deviation gives an X^2 value of 16.112 and a very low value for P. Calculating the linkage from the total population, a cross over of 34.22%

[1]Contribution from the Division of Agronomy, University of California, Davis, Calif. Received for publication April 27, 1940.

[2]Associate Agronomist.

[3]Figures in parenthesis refer to "Literature Cited", p. 541.

TABLE 1.—F_3 *Data from the various crosses of wheat involving the Martin and Turkey factors for resistance to bunt.*

Crosses	Types of row	No. of F_3 rows observed	No. of rows expected 15:1 ratio	P	No. of rows expected 34.22% C.O.	P
Martin × Turkey 3055	Resistant and segregating	183	178.1		184.4	
	Susceptible	7	11.9		5.6	
	Total	190	190.0	>0.10	190.0	>0.5
Martin × Turkey 1558	Resistant and segregating	179	171.6		177.6	
	Susceptible	4	11.4		5.4	
	Total	183	183.0	>0.03	183.0	>0.5
Sherman × Turkey 3055	Resistant and segregating	136	131.2		135.9	
	Susceptible	4	8.8		4.1	
	Total	140	140.0	>0.05	140.0	>0.8
Martin × Oro	Resistant and segregating	101	97.5		101.0	
	Susceptible	3	6.5		3.0	
	Total	104	104.0	>0.10	104.0	>0.99
Martin × Turkey 1558B	Resistant and segregating	114	110.6		114.5	
	Susceptible	4	7.4		3.5	
	Total	118	118.0	>0.20	118.0	>0.7
Martin × Turkey 2578	Resistant and segregating	116	111.6		115.3	
	Susceptible	3	7.4		3.7	
	Total	119	119.0	>0.10	119.0	>0.7
Total all crosses	Resistant and segregating	829	800.6		829.0	
	Susceptible	25	53.4		25.0	
	Total	854	854.0	Very small	854.0	

was obtained. When the expected numbers of susceptible rows were calculated for the individual crosses using the above linkage value, they were in close agreement with those obtained. The P values are shown even though in a number of cases they were based on expected values of less than 5.

The number of rows for the individual crosses was too small to show that the deviations between the numbers of rows obtained and those expected on the basis of the 15:1 ratio are greater than might be

expected from chance. However, when all the data are considered together the deviation becomes very significant. This deviation may be accounted for by linkage between the Martin and Turkey factors. Using a cross over of 34.22%, the expected numbers for all crosses are much nearer those obtained than when the two factors are considered to be independent.

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FERTILIZING VALUE OF SPENT PHOSPHATE CATALYST[1]

G. S. FRAPS[2]

A CATALYST containing phosphoric acid is used in the manufacture of gasolene from petroleum. Several hundred tons of the spent phosphate catalyst may accumulate at a manufacturing point during the course of a year, and the question arose as to its suitability for use as a fertilizer. Chemical analyses and pot experiments were made to secure the necessary information.

CHEMICAL COMPOSITION AND AVAILABILITY

The chemical composition of six samples is given in Table 1. The analysis of the samples gives from 40.93 to 54.46% of total phosphoric acid (P_2O_5) with the exception of one sample which had been exposed to the weather for some months and contained only 24.14%. These analyses were made by the A.O.A.C. method of ignition with magnesium nitrate. When nitric and hydrochloric acids were used as a solvent, the amounts of total phosphoric acid found were both low and erratic, such as 30.15% compared with 40.93% by ignition with magnesium nitrate.

The catalyst was almost completely soluble in ammonium citrate by the official A.O.A.C. method. The catalyst therefore has a high content of available phosphoric acid.

Three analyses of the catalyst for silica gave from 56% to 58.8% which was made insoluble by evaporating the solution to dryness. It is acid, having an acid-base balance of 561A to 836A by the tentative A.O.A.C. method. The analyses indicated that the spent catalyst has a high content of chemically available phosphoric acid.

TABLE 1.—*Chemical composition of spent phosphate catalyst.*

Description	Total P_2O_5 %	Insoluble P_2O_5 %	Available P_2O_5 %	Silica %	Acid-base balance %	Total P_2O_5 acid-sol. %
Fresh not weathered..	40.93	0.40	40.53	58.80	561A	30.15
Not weathered.......	54.46	0.40	54.06	—	—	35.96
Not weathered.......	54.16	0.31	53.85	—	678A	30.26
Not weathered.......	47.18	0.81	46.37	56.01	836A	—
Weathered..........	24.14	0.44	23.70	—	—	16.00
Not weathered.......	45.68	1.07	44.61	57.18	745A	—

AVAILABILITY TO PLANTS

The availability of the phosphoric acid of the spent catalyst was compared with that of superphosphate by means of the usual pot experiments with plants, with the exception that the conclusions

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[2]Chief of the Division of Chemistry. Technical assistance in this work was rendered by T. L. Ogier and Dr. P. F. Macy.

are based upon the quantity of phosphoric acid taken up by the plants instead of on the dry weight of the plants.

The crops were grown in pots containing 2,000 grams of subsoil and 3,000 grams of pure quartz sand. The four soils used were as follows: Soil A, Randall clay, 7- to 17-inch depth, from Texas Substation No. 19, Carrizo Springs, Texas; soil B, Webb fine sandy loam, 10- to 17-inch depth, from Substation No. 19; soil C, Maverick fine sandy loam, 7- to 14-inch depth, from Substation No. 19; and soil D, Elwood fine sandy loam, 14- to 21-inch depth, from Fannin County. Each pot received 1 gram of ammonium nitrate and 1 gram of potassium sulfate. No other addition was made to two pots, while two other pots received additions of 0.100 gram available phosphoric acid (P_2O_5) as superphosphate and two more received 0.2037 gram available phosphoric acid in the form of spent catalyst. At the time the experiments were begun, the percentage of available phosphoric acid was not known on account of difficulties in the analysis.

Equal quantities of seed per pot were planted and the pots kept in a greenhouse and watered three times a week. After 2 months, the first crop of corn was harvested, the additions of fertilizer repeated, and a second crop of kafir planted. The kafir was harvested in 2 months. The crops were dried, weighed, and analyzed for phosphoric acid.

The dry weights of the crops are summarized and given in Table 2. The weights of the crops which received the spent catalysts are larger than those which received the superphosphate, but the quantity of available phosphoric acid added was also larger.

The results for comparative availability of the phosphoric acid of the two substances are also summarized in Table 2. For each soil, the average quantity of the phosphoric acid found in corn from the two

TABLE 2.—*Weights of crops produced and percentages of phosphoric acid recovered from superphosphate and spent phosphate catalyst.*

Soil	Crop	Dry weight of crop, grams			Phosphoric acid (P_2O_5) recovered, %	
		No treatment	Super-phosphate	Catalyst	Super-phosphate	Catalyst
A	Corn	5.5	28.7	30.0	36.6	31.3
	Kafir	12.7	29.5	31.2	59.7	48.8
B	Corn	1.8	16.9	29.7	27.4	26.5
	Kafir	4.0	28.1	33.3	64.8	53.5
C	Corn	2.1	21.1	27.5	27.7	26.2
	Kafir	2.4	10.7	12.1	31.9	21.9
D	Corn	2.6	9.0	10.4	15.2	17.3
	Kafir	6.4	24.7	27.6	38.9	34.7

pots which did not receive phosphates was subtracted from the average quantity in the corn which received phosphate, and the remainder was assumed to be the phosphoric acid taken up by the corn from the phosphate. This remainder was divided by the quantity of available phosphoric acid used in the fertilizer to secure the percentages taken from the phosphate used.

Since the tests were made with four soils, involving a crop of corn and a crop of kafir in each, eight comparisons were possible. The percentage of phosphoric acid removed by the crops from the spent catalyst was less than that removed from the superphosphate in seven of the eight tests, but the differences were not large in most cases. In evaluating these results, the fact must be considered that twice as much available phosphoric acid was added in the catalyst as in the superphosphate. Taking this into consideration, the conclusion can be drawn that the phosphoric acid of the spent catalyst has a high availability to corn and kafir, and that its availability is as high, or nearly as high, as that of superphosphate.

SUMMARY

Spent phosphate catalyst is a by-product derived from the manufacture of petroleum products. When fresh, it contains from 40 to 54% available phosphoric acid (P_2O_5), and about 58% insoluble material (silica). The weathered catalyst may contain only 24% phosphoric acid. It is acidic, having an acid-base balance equal to 561 to 836 pounds of calcium carbonate per ton. Ignition with magnesium nitrate gives correct results for total phosphoric acid, but solution in acids gives results which may be 10% too low. The percentage of the phosphoric acid taken up by corn and kafir in eight tests on four soils was nearly as high as from superphosphate. The phosphoric acid of spent phosphate catalyst has a high order of availability to plants, being much like that of superphosphate.

THE ESTABLISHMENT OF BAHIA GRASS, *PASPALUM NOTATUM*[1]

GLENN W. BURTON[2]

DURING the past few years a number of cattle men in Florida and South Georgia have purchased and planted seed of Bahia grass, *Paspalum notatum*, Flügge. Most of this seed has not been scarified. It has been broadcast usually in fair to poor seedbeds and no effort has been made to cover the seed. Although some good Bahia grass pastures have been established in this manner, several years are required and some failures have been experienced. Low viability and poor adaptability of the seed planted, winter injury, and drought probably featured in some of these failures.

Numerous greenhouse studies[3] have demonstrated that Bahia grass seed germinating less than 5% in 3 months can be made to germinate over 50% in 10 days when properly scarified with sulfuric acid. In an effort to determine the value of seed scarification in field plantings and to obtain some information on methods of establishment, the following field experiments were conducted at Tifton, Georgia, in 1939.

On March 28, 1939, scarified and unscarified seed of common Bahia, bulked seed harvested from locally grown plants which originated from foreign commercial sources, and Paraguay Bahia, the latter a cold-resistant strain having seeds about two-thirds the size of common Bahia, were planted in 3 x 42 foot plots on a well-prepared Tifton sandy loam in the manner described in Table 1. The scarified seed used in this study were placed in a small drum similar to one previously described by the author[4] and were treated for 25 minutes in crude H_2SO_4 used in the manufacture of superphosphate fertilizer (specific gravity 1.69, about 78% H_2SO_4). The fertlizer was distributed on the surface and raked in before the seed was planted. The "broadcast and harrowed" plot was raked after the seeding to simulate the covering which would have resulted from a light harrowing with a spike-toothed harrow. A columbia nursery drill was used to drill, cover, and pack the seed planted in rows.

In addition to the treatments described in Table 1, plots were established in which the same number of seeds were planted per linear foot in rows 1, 2, and 3 feet apart. All rows spaced 2 and 3 feet apart were cultivated with no hand weeding three times during the summer of 1939. The middle row of the 1-foot spacing could not be cultivated. The weed growth was cut back even with the tips of the grass leaves twice during the season.

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[1]Cooperative investigations of the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, the Georgia Coastal Plain Experiment Station at Tifton, Georgia, and the Georgia Experiment Station, Experiment, Georgia. Received for publication May 27, 1940.

[2]Associate Geneticist, U. S. Dept. of Agriculture, Tifton, Georgia.

[3]BURTON, GLENN W. Scarification studies on southern grass seeds. Jour. Amer. Soc. Agron., 31:179–187. 1939.

[4]*Loc. cit.*

TABLE 1.—*The influence of seed scarification and planting methods upon the establishment of common Bahia (C. B.) and Paraguay Bahia (P. B.), Paspalum notatum strains, as measured by seedling counts made on April 24, 1939, one month after planting.*

Treatment No.	Seeding rate, lbs. per acre	Fertilizer 7–14–7, rate, lbs. per acre	Depth seed were planted, inches	Method of planting	No. of seedlings per sq. ft. or per ft. of row		No. of seedlings per 100 seed planted	
					C.B.	P.B.	C.B.	P.B.
				Seed Not Scarified				
1	28	270	⅜	Drilled, covered, and packed	7	28	3.1	8.0
				Seed Scarified With H_2SO				
2	28	270	Surface	Broadcast and not harrowed	11	6	11.6	4.1
3	28	270		Broadcast and harrowed	40	39	42.1	26.5
4	28	270	Surface	Drilled on surface and packed	36	50	12.6	11.3
5	28	270	½	Drilled, covered and packed	71	152	24.9	34.5
6	28	270	1	Drilled, covered and packed	80	94	28.0	21.3
7	28	270	⅜	Drilled, covered and packed	89	139	31.2	31.5
8	28	None	⅜	Drilled, covered and packed	125	201	52.6	45.6
9	13	270	⅜	Drilled, covered and packed	51	101	39.0	49.8
10	13	None	⅜	Drilled, covered and packed	72	96	55.0	47.3
11	8.4	270	⅜	Drilled, covered and packed	35	71	41.2	54.2
12	8.4	None	⅜	Drilled, covered and packed	44	62	51.8	47.3

On March 30, two days after the planting was made, 0.14 inch of rain was recorded. Six-hundredths inch of rain fell on April 3 and 3.83 inches were recorded on April 6. A total of 6.41 inches of rain were quite well distributed over the period from March 28 to April 24. On April 24 the number of seedlings per square foot of the broadcast plots or per linear foot of row were counted in three random areas in each plot. The average of these counts for the various treatments, together with the calculated number of seedlings per 100 seeds planted, have been presented in Table 1.

A comparison of treatments 1 and 7 in Table 1 indicates that scarified seed of common Bahia produced over 10 times as many plants per 100 seeds planted as the unscarified seed. In agreement with our greenhouse studies, this field planting revealed that unscarified seed of Paraguay Bahia will germinate better than unscarified seed of common Bahia. Thus, scarification increased the germination of Paraguay Bahia only about four times.

Treatments 2 and 3 in Table 1 suggest that covering broadcast seed by harrowing will increase the number of seedlings produced per 100 seeds planted from three to six times. Plant counts made on three randomized areas in each plot on January 4, 1940, revealed an average of 9 plants of common Bahia and 11 plants of Paraguay Bahia per square foot in the "Broadcast and not harrowed" plot and 26 and 34 plants, respectively, in the "broadcast and harrowed" plots. Likewise, a comparison of treatments 4 and 7 in Table 1 proves quite conclusively that covering Bahia grass seed results in a substantial increase in the number of plants produced per pound of seed planted.

A study of the results obtained for the various depths of planting indicates that in this test planting the seed at a depth of 3/8-inch produced the most seedlings per 100 seeds planted. It is apparent, however, that planting the seeds 1 inch below the surface produced more seedlings per 100 seeds planted than surface planting (compare treatments 4 and 6 in Table 1). Thus, since the seed planted at a depth of 1 inch in this test germinated first, it would seem that seed planted in light sandy soils or during dry periods might well be placed an inch below the surface of the soil.

Table 1 shows that fertilizer applied at the time of seeding, although not placed in intimate contact with the seed, frequently decreased the germination of Bahia grass seed. These results suggest that drilling commercial fertilizer and Bahia grass seed together in the same row may reduce its germination materially.

In this test scarified common Bahia grass seed planted at the rate of 8.4 pounds of seed per acre in 3-foot rows produced an average of 44 seedlings per linear foot or row. Obviously good seed properly scarified could be planted in 3-foot rows in a well-prepared seedbed at rates much lighter than 8.4 pounds per acre.

The influence of various treatments upon total top growth in 1939 was determined in January 1940 by digging up all plants in 3 feet of each row, removing the roots, drying, and weighing the tops. These yields showed the following relationships: Rows grown from scarified seed yielded about twice as much as rows from unscarified

seed. The better stand and earlier establishment of the rows from scarified seed were largely responsible for this difference. Since the rows seeded at 8.4 pounds per acre yielded as much as those seeded at 28 pounds per acre, it is apparent that the heavier seeding repre-presented in this case a waste of 19.6 pounds of seed per acre. Fertilization at the time of seeding, while increasing the average yield of all rows fertilized, failed to do so consistently.

That the yields of the middle rows in the 1-, 2-, and 3-foot spacings would differ was suggested by the appearance of these plots on July 20, 1939, as shown in Fig. 1. Since the 2- and 3-foot spacings yielded

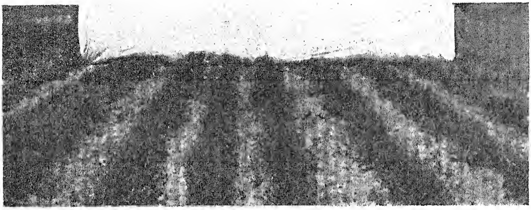

FIG. 1.—The influence of row spacing and cultivation upon the growth of Bahia grass. On the left, the 1-foot spacing, center row not cultivated; in the center, the 2-foot spacing; on the right, the 3-foot spacing. Photographed four months after seeding.

practically the same per linear foot of row, it is evident that the 2-foot spacing actually produced 50% more top growth per square foot than the 3-foot spacing. On the unit area basis the 2-foot spacing produced 4 times as much top growth as the 1-foot spacing. Since the 2-foot spaced rows were cultivated and the middle 1-foot row was not, most of this increase must be credited to three cultivations made during the summer. As shown in Fig. 1, the rows spaced 2 and 3 feet apart produced seed equally well in 1939, while the middle row of the 1-foot spaced rows formed practically no seed heads.

On April 28, 1939, seed of six promising grasses at Tifton, Georgia, were planted in 25-foot rows in quadruplicate, in a well-prepared Tifton sandy loam. Abundant rainfall followed, favoring the germination of all seeds planted. For these six grasses the following dates of emergence were recorded: Common Bahia grass (scarified seed), May 7; *Paspalum malacophyllum* Trin., May 7; Paraguay Bahia grass (scarified seed), May 11; Vasey grass, *Paspalum urvillei* Steud., May 13; Dallis grass, *Paspalum dilatatum* Poir, May 15; and carpet grass, *Axonopus affinis* Chase, June 5. Thus there is little doubt but that good Bahia grass seed, when properly scarified, will germinate as soon, if not sooner, than other grasses such as carpet and Dallis grass now being planted in this area.

SUMMARY AND CONCLUSIONS

Since it is recognized that preparing good seedbeds, drilling and covering seed, and cultivation will be highly impracticable in many areas where Bahia grass will be planted, the results presented here will have their principal value in assisting the formulation of a planting procedure for each set of conditions. With full recognition of these specific problems these results would seem to justify the following conclusions: Regardless of the manner in which the seed is planted, acid scarification will greatly increase the number of plants obtained per pound of seed. With the present high price of seed, drilling seed ¼ inch to 1 inch deep in well-prepared seedbeds where possible, or covering seed by the use of disk harrows, etc., in areas where good seedbeds cannot be made should pay dividends. For those interested in seed production, or for farmers with more time than cash, drilling 4 to 6 pounds of good scarified seed in rows 2 feet apart followed by several cultivations should prove to be a very economical method of establishing the grass. If scarified seed of Bahia grass is planted properly, there is no doubt but that it can be established from seed as readily as other grasses grown in this area.

NOTE

A SATISFACTORY GRINDER FOR PREPARING PLANT TISSUE FOR RAPID CHEMICAL TESTS

ONE of the obstacles in the way of the advancement of rapid chemical analyses in plant tissue tests has been a satisfactory method of obtaining an accurately extracted sample. By the use of a "liquifier" (Waring Corp., 1697 Broadway, N. Y.)[1] a most satisfactory emulsified sample can be obtained.

The author has found the following procedure satisfactory. Place 5 grams of roughly chopped plant tissue or stems (even very woody tissue is readily emulsified) in the container, add 100 mls of sodium acetate solution (pH 5.0), 0.125 N for sodium and 0.167 N for acetate, and ¼ teaspoonful of charcoal (Darco brand) and run the machine from 3 to 5 minutes. The liquified mass is then filtered through No. 1 Whatman filter paper.

Tests for various constituents are carried out as described for soil tests in Bulletin 95, Virginia Truck Experiment Station. However, in the case of potash further dilution of the extract is necessary.—JACKSON B. HESTER, *Soil Technologist, Department of Agricultural Research, Campbell Soup Co., Riverton, N. J.*

[1]Several other makes of similar equipment are available.

AGRONOMIC AFFAIRS

CHECK SOILS FOR COLLABORATIVE SOIL TESTING

A SERIES of 31 check soils was assembled last year by the Sub-committee on Soil Testing of the Fertilizer Committee of the American Society of Agronomy. Sets of samples may be obtained upon request to Dr. H. G. Byers, Soil Chemistry Division, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C. There is no charge, except that the package is sent by express, collect.

Collaborators obtaining sets of the check soils are expected to send copies of their results to M. F. Morgan, Connecticut Agricultural Experiment Station, New Haven, Conn., Chairman of the Sub-committee. They will be supplied with preliminary reports of "composite" results to date and will receive copies of all further data concerning the various soils. The Sub-committee on Soil Testing plans to present a detailed study of these results at the winter meeting; hence, it is urgent that reports be filed during the next two or three months. Results received after October first cannot be included. Twenty-six collaborators have already reported, but it is hoped that the data of at least twice this number will be available in the final tabulation.

NEWS ITEMS

THE following changes became effective May 1, 1940, in the Agronomy Departments of the Ohio Agricultural Experiment Station and the Ohio State University: Robert M. Salter has been appointed Associate Director of the Ohio Agricultural Experiment Station. Dr. Salter continues as Chief in Agronomy at the Experiment Station. At the Ohio State University R. D. Lewis has been appointed Chairman of the Department of Agronomy and continues as Associate in Agronomy at the Experiment Station. C. A. Lamb, Associate in Agronomy at the Experiment Station, also has been appointed a member of the teaching staff (Cereal Crops) of the Department of Agronomy of the Ohio State University. Effective July 1, 1940, Robert Q. Parks becomes an Assistant in Agronomy (Soil Fertility) at the Experiment Station and Instructor in Agronomy at the University.

The cooperative relationships between the Departments of Agronomy of the Ohio Agricultural Experiment Station and the Ohio State University are to be continued as in the immediate past.

PROFESSOR O. MCCONKEY of the Department of Field Husbandry, Ontario Agricultural College, has been called to mobilize a battery of field artillery in the Royal Canadian Artillery. Major McConkey may be reached through the Ontario Agricultural College at Guelph.

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THE ROLE OF SOIL ORGANIC MATTER IN REFORESTATION[1]

S. A. WILDE AND W. E. PATZER[2]

THE importance of soil organic matter in the promotion of soil fertility has received the attention of both practical and scientific agriculturists for many centuries (10).[3] Nevertheless, there still exists surprisingly little information on the role which soil organic matter plays in practical silviculture, particularly in the survival and growth of forest plantations. Why forestry research and reforestation practice in both America and Europe have neglected this important factor is difficult to comprehend. The indifference may be attributed to comparatively limited experience in the reforestation of old cut-over areas, the complicating co-influence of mineral colloids, occurrence of organic matter as incorporated humus as well as surface litter, certain analytical difficulties in the determination of organic matter, and fairly satisfactory growth of some mycorrhizal species on humus-deficient soils.

At the present time, reforestation in this country is, in the main, practiced on cut-over or burned-over lands depleted of organic matter and therefore greatly reduced in absorbing capacity and nutrient content. A large portion of the area available for reforestation is comprised of coarse sandy soils having a negligible content of mineral colloids; the content of organic matter in such soils is particularly of great importance. Some humus-loving species, such as spruce and white pine, seem to require for their successful growth a certain amount of organic matter aside from the supply of water and mineral plant nutrients.

These considerations served as an impulse in undertaking the present study. Within available means, an effort was made to establish a

[1]Contribution from Soils Department, University of Wisconsin, Madison, Wis., in cooperation with the Wisconsin Conservation Department. Publication authorized by the Director of the Wisconsin Agricultural Experiment Station. The study was supported in part by Works Progress Administration funds through the Natural Science Project. Received for publication April 25, 1940.

[2]Associate Professor and Chemist, respectively. The writers are indebted to Mr. R. W. Knutson, U. S. Forest Service, Region 9, and Mr. S. B. McCoy, Wisconsin Conservation Department, for their wholehearted cooperation in different phases of this study.

[3]Figures in parenthesis refer to "Literature Cited", p. 562.

general relationship between the content of soil organic matter and the productivity of cut-over lands, to correlate organic matter content with planting possibilities, and to work out an analytical procedure acceptable to forestry practice. The investigations were largely confined to central and northern Wisconsin with four silviculturally important conifers, namely, jack pine, *Pinus banksiana*, red pine, *P. resinosa*, white pine, *P. strobus*, and white spruce, *Picea glauca*.

RELATION OF SOIL ORGANIC MATTER TO PRODUCTIVITY OF CUT-OVER LANDS

A study was made of the organic matter and nutrient content of outwash and pitted outwash sandy soils derived largely from granitic rocks. The geological origin and textural characteristics of these deposits were believed to be sufficiently uniform to permit an investigation of the relations between organic matter, total nitrogen, available phosphorus, and available potassium. The total number of samples analyzed exceeded 40. In order to get soils with higher contents of organic matter, several selectively logged areas were included in the study. Organic matter was determined either by the standard chromic acid procedure (3), or by a modification of Schollenberger's (7) method described in this paper. Kjeldahl (A. O. A. C., 2), Truog (8), and Volk-Truog (9) methods were used for the determination of total nitrogen and available phosphorus and potassium, respectively. The results related to the 7-inch surface layer of soil are presented in Figs. 1 and 2.

The results suggest that the deficiency of all nutrients becomes especially acute when the content of organic matter drops below 2%. According to the agronomist's saying, "Nitrogen spells organic matter." In sandy forest soils, with their revolving fertility renewed through the annual leaf-fall, the organic matter content appears to be nearly synonymous with the content of all available nutrients.

Organic matter retains considerable amounts of water (6). Although a portion of this water is not available to trees (4), the soils with a high organic matter content may be less subject to drought injury than humus-deficient soils.

RELATION OF SOIL ORGANIC MATTER CONTENT TO SURVIVAL AND GROWTH OF PLANTATIONS

The limited number of plantations having uniform physiographic conditions makes it very difficult to study the growth of seedlings in relation to the organic matter content of soil on a statistical basis. This problem involves not only the co-influence of site factors, but the occurrence of critical weather conditions, origin of stock and its handling in the field.

The first attempts of the writers, confined to the area of central Wisconsin, gave but one result worthy of consideration, namely that jack pine and red pine deteriorate in growth when the content of soil organic matter drops below 0.5 and 2.0%, respectively. The wind-eroded "blow holes" occurring in spots within plantations furnished material from which this information was derived (Fig. 3).

In the fall of 1939, several members of the U. S. Forest Service called the attention of the writers to the extremely low content of organic matter in soils of the Bayfield Barrens, Chequamegon National Forest. This area presented nearly ideal conditions for the study of the problem. It comprises thousands of acres of podzolized sands on which reforestation has been carried on since 1930, and a complete history of the plantations was available.

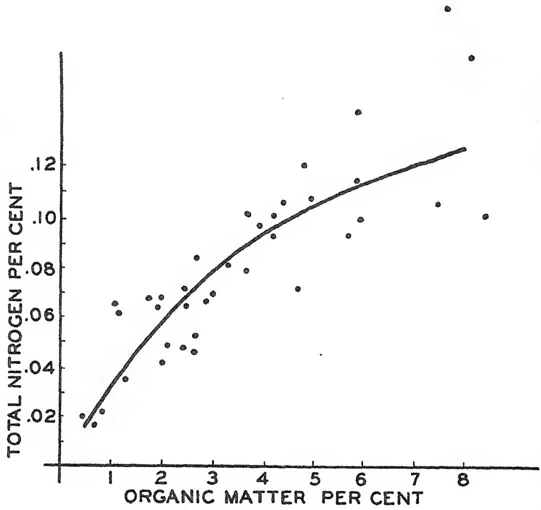

FIG. 1.—Relation of total nitrogen to organic matter in cut-over sandy soils of Wisconsin (Plainfield and Vilas series).

The collection of samples was limited primarily .to plantations characterized by either poor or very satisfactory tree growth. A few plantations established by the State Forestry Department in adjoining counties were also included in this study. The results of soil analyses and the corresponding data for the survival and average annual growth of jack and red pine are given in Figs. 4 and 5.

Although the data vary considerably, they indicate an adverse influence of deficient organic matter upon both survival and rate of growth of the species studied. The results obtained from soils with a low content of organic matter are, of course, of greatest practical significance. The need for further observations, with a much greater number of sample areas, is nevertheless obvious.

RELATION OF SOIL ORGANIC MATTER CONTENT TO PLANTING POSSIBILITIES

The results obtained in the study of jack and red pine plantations, as well as some incidental observations of white pine and white spruce plantations, suggest that the following minimum contents of soil organic matter are required by these species: Jack pine, 0.6%; red pine, 1.8%; white pine, 2.5%; white spruce, 3%. These figures ap-

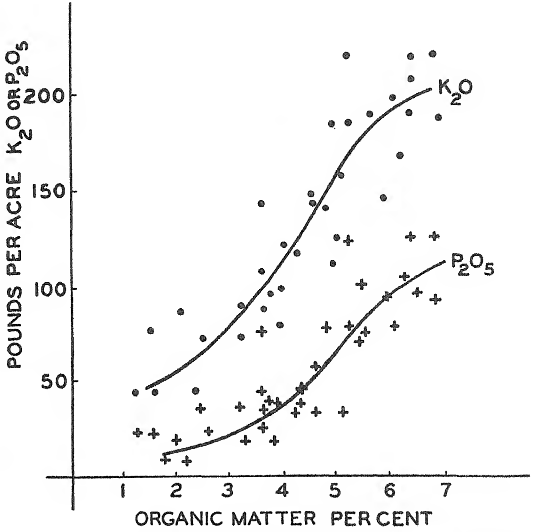

FIG. 2.—Relation of available phosphoric acid and available potash to organic matter in cut-over sandy soils of Wisconsin (Plainfield and Vilas series).

proximate the *absolute minimum requirements* which should be respected in planting, regardless of other conditions. A sufficiently high content of organic matter is of particular importance in the growth of spruce, i.e., a species with saprophytic tendencies.

Since the influence of organic matter supplements, within certain limits, the effect of mineral colloids (11), a coordinated consideration of both of these factors should provide a wider selection of planting sites, and, at the same time, would give more assurance of success.

General observations indicate that the absorbing or base exchange effects of soil organic matter are at least two and one-half times as

FIG. 3.—Fourteen-year old red pine plantation on outwash sand deficient in organic matter; average height 6 feet. Red pine plantations of the same age on more productive soils in the vicinity attained an average height of 15 feet or more.

great as those of fine soil material, i.e., material less than 0.05 mm in diameter. Hence, as regards these effects, it may be estimated for practical purposes that one per cent of organic matter is equivalent to 2.5% of fine soil material. This implies that a considerably lower content of mineral colloids is adequate for successful planting on soils high in organic matter. For example, on such soils under Wisconsin conditions, the minimum contents of the fine soil material

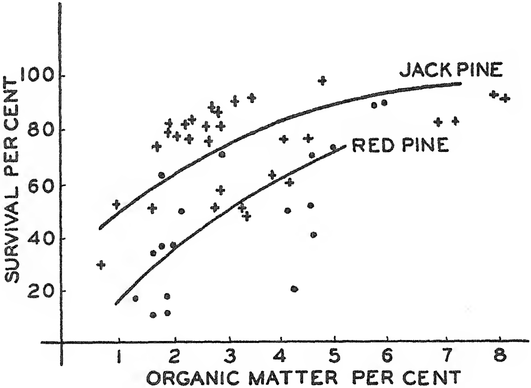

FIG. 4.—Relation of survival of jack pine and red pine plantations to the content of organic matter in podzolic sandy soils of northern Wisconsin. The general trend is indicated by free-hand curves.

ordinarily necessary could be lowered to the following values: Jack pine, 3%; red pine, 7%; white pine, 12%; white spruce, 25%.

A scheme of planting possibilities for four coniferous species under Wisconsin climatic conditions and for soils not influenced by ground water is given in Fig. 6. The slanted lines represent the minimum acceptable ranges of fine soil material and organic matter for each species. The ordinate and abscissa values for any point on a species line give the minimum acceptable values of each constituent for that

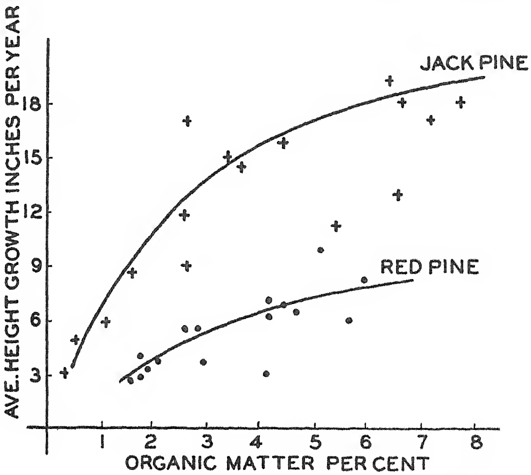

FIG. 5.—Relation of height growth of jack pine and red pine plantations to the content of organic matter in podzolic sandy soils of northern Wisconsin. The general trend is indicated by free-hand curves.

species. Therefore, the lines of species which touch the intersection of perpendiculars erected from the coordinates, or fall within the area enclosed by the perpendiculars, indicate that these species are suitable for planting on the soil in question. A transparent right triangle will be found helpful in using the diagram.

For example, if the soil analyzes 20% of silt and clay and 2.7% of organic matter, then the site is suitable to jack pine, red pine, and white pine, but not white spruce. The graphs may also be used in a somewhat different manner. Suppose the soil of a large outwash tract is known to contain about 10% of silt and clay particles; then the sites suitable to red pine should have at least 3% of organic matter.

METHOD OF SOIL SAMPLING

Sampling for the determination of the organic matter content in forest soils presents its own problem. In weakly podzolized or in brownearth soils with a mull type of humus, the litter decomposes rapidly and the organic matter is thoroughly mixed with the mineral soil. On the other hand, in podzol soils organic matter occurs as a

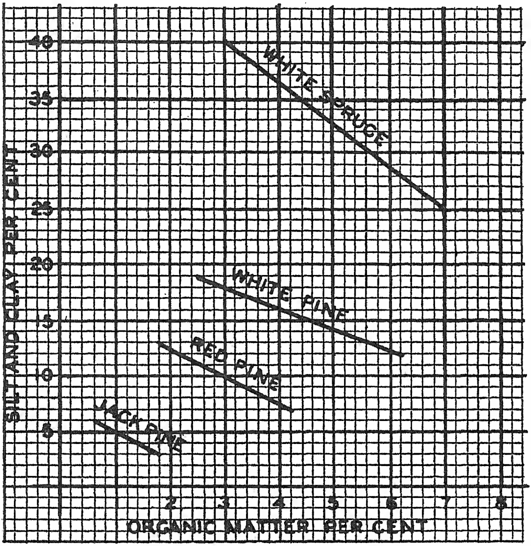

FIG. 6.—Planting possibilities of northern conifers in relation to soil texture and content of organic matter under Wisconsin conditions. The lines of species which touch the intersection of perpendiculars erected from the coordinates, or fall within the area enclosed by the perpendiculars, indicate that these species are suitable for planting on the soil in question.

surface deposit, including undecomposed litter and a partly decomposed duff layer underlain by a humusless leached horizon. In between these two extremes, there are numerous transitions, i.e., soils in which some organic matter occurs as free remains and some is incorporated with the mineral soil. It is obvious that in sampling such heterogeneous soils proportionate amounts of material cannot be secured by means of an auger or spade. The sampling by separate horizons involves difficulties of measuring the thickness of the horizons, extra

determinations, and rather lengthy calculations. Therefore, the most suitable method seems to be the use of a sampling tube which removes a representative cross-section of the entire soil profile to a definite depth.

In an attempt to devise a tool adapted to sampling, a number of modifications have been made and tried in the field. The combination of the soil auger handle with Pessin's tube (5), made of black iron pipe, proved to be the most successful. The best dimensions appeared to be a diameter of one-inch bore with a one-half inch slit; tubes of greater size caused difficulties in gravelly soils, whereas tubes of smaller size became plugged by the soil and acted as a plunger. A sampling length greater than 7 inches was found unnecessary, as the infiltration of humus seldom exceeds 6 inches. Fig. 7 shows the successful model together with other models which proved to be unsatisfactory.

The sampling is accomplished by pressing the tube into the soil. In stiff soils, a rotating movement in auger-like fashion may be helpful, but it is usually better to remove what soil has collected and continue in the same hole with the emptied tube. The removal of soil is facilitated by the use of a bent piece of iron which fits the slit.

The soil samples are placed in half-pint cardboard boxes. Two borings usually give a sample of sufficient size.

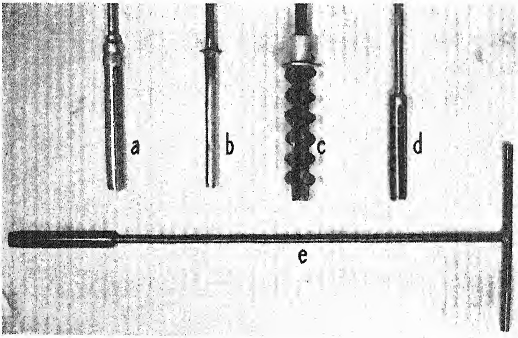

FIG. 7.—Models of sampling tubes tried: (a) A modification of King's tube provided with a swinging door to facilitate the removal of soil; the door was found to be unnecessary; (b) A narrow, half-inch bore tube which would be ideal for collecting samples from nursery beds, but often becomes plugged with soil and acts as a plunger; (c) Auger-like tube; proved to be an expensive and inefficient tool; (d) Shortened Pessin's tube of one inch bore with half-inch slit; found to be a simple and efficient sampler; (e) The same tube on a 2-foot long auger rod; shorter rods caused inconvenience in sampling.

PROCEDURE FOR ORGANIC MATTER DETERMINATION

A survey (1) of the existing procedures for the determination of soil organic matter indicated that the chromic acid titration method devised by Schollenberger (7) has, because of its simplicity, many advantages for practical work. The following adaptation of this method has been found to give reliable data and is recommended for rapid, approximate work in reforestation practice:

The air-dry soil sample is passed through a 20-mesh screen. With gravelly soils, the percentage of coarse material is determined on a gross balance in the usual manner. A representative portion is ground with mortar and pestle or with a steel rocker on an extra hard steel plate until all of the particles pass through a 100-mesh screen. A measuring spoon, calibrated to deliver a one-half gram sample, is filled heaping full of the soil. After packing the soil with a spatula, the spoon is struck off level full. The sample is transferred to a dry 1 x 6 inch Pyrex test tube. One cc of potassium bichromate solution is measured with a pipette and transferred to the tube. Fifteen cc of the sulfuric-phosphoric acid mixture are added, thoroughly washing down the soil particles.

The tube is placed for 10 to 15 minutes in a bath of 85% phosphoric acid heated to 160° C. The contents of the tube are agitated occasionally. Ordinarily, a battery of twelve tubes is digested in the same bath. After digestion is complete, the tube is removed, allowed to cool for several minutes, and then placed in flowing cold water. The cooled contents of the tube are poured into a beaker. Four rinsings of the tube with water are necessary for complete transfer. The solution in the beaker is diluted to 200 cc. Five drops of diphenylamine indicator, and a quarter teaspoonful of sodium fluoride powder are added. Then 0.2 N ferrous ammonium sulfate solution is added slowly from a burette with stirring until a clear dark blue color develops. Another drop of the ferrous ammonium sulfate solution is added and the contents are vigorously stirred for 30 seconds or more.

This process is continued until the blue color changes to green. A blank (without soil) is prepared using the same amounts of bichromate solution and acid mixture as in the regular test. Titration is made in the usual manner. The difference between the titration figures of the blank and unknown solution multiplied by 0.125 and divided by the weight of the sample in grams gives the percentage of organic matter.

If the soil sample contains more than 2.5% of organic matter, 2 cc of bichromate solution and 30 cc of acid mixture should be used in the digestion. The digested solution should then be diluted to 400 cc. Soils having contents of organic matter higher than 5% will require still greater amount of reagents, and hence greater dilution. Experience will teach the desirable amount of acid needed under various conditions.

The accuracy of the method as regards duplication of results is illustrated by the data of Table 1.

If titration is inconvenient, it may be replaced by a colorimetric procedure. The cooled, digested solution is diluted to 75 cc and allowed to settle. The reduction of chromic ions (orange) to the chromous state (green) produces a variation of color ranging from bright

TABLE 1.—*Duplicate determinations of the content of organic matter in cut-over sandy soils by the modified Scholenberger chromic acid reduction method.*

No. of soil sample	1st determination %	2nd determination %	Difference %	No. of soil sample	1st determination %	2nd determination %	Difference %
1	1.25	1.24	0.01	9	2.20	2.06	0.14
2	1.71	1.71	—	10	3.03	3.30	0.27
3	1.53	1.53	—	11	2.15	2.05	0.10
4	1.90	1.86	0.04	12	2.55	2.60	0.05
5	3.00	3.02	0.02	13	1.55	1.70	0.15
6	4.22	4.12	0.10	14	1.60	1.45	0.15
7	4.15	4.50	0.35	15	1.95	1.95	—
8	4.57	4.50	0.07	16	2.75	2.68	0.07

orange to bluish-green. Comparison of the unknown solution with a set of standards, or with a suitable color chart gives the content of organic matter within an accuracy of about 0.25%. With certain adjustments, the comparison of colors may be facilitated by the use of a photoelectric cell.

REAGENTS NEEDED FOR ORGANIC MATTER DETERMINATION

Potassium bichromate solution.—Dissolve 9.807 grams of oven-dry $K_2Cr_2O_7$ in 75 cc of water and make up to 100 cc in a volumetric flask. Keep this solution tightly stoppered to prevent evaporation.

Sulfuric-phosphoric acid mixture.—Add by volume 2 parts of concentrated sulfuric acid, C. P. grade, to 1 part of 85% phosphoric acid U.S.P. grade.

0.2 N ferrous ammonium sulfate solution.—Dissolve 78.44 grams of $FeSO_4(NH_4)_2SO_4.6H_2O$ in 500 cc of water containing 20 cc of concentrated H_2SO_4 and make up to 1 liter. Keep this solution in a tightly stoppered brown bottle.

Diphenylamine indicator.—Dissolve 0.5 gram in 100 cc of concentrated H_2SO_4 and transfer into a 200 cc beaker containing 20 cc of water. Store in a tightly stoppered brown bottle.

DISCUSSION

In the past, the application of soil analysis in the selection of planting sites has been limited largely to two factors, namely, reaction and content of mineral colloids. The lack of knowledge concerning the soil organic matter content led to the use of estimated values. As a consequence, the sites with a high content of organic matter were not fully utilized, whereas on those with a low content, planted stock was exposed to the danger of drought or malnutrition.

During the past few years a number of foresters have questioned the adequacy of a knowledge of the mineral colloid content alone and have emphasized the role which organic colloids may play in the survival and growth of plantations. Considering the cost of reforestation, as well as the discouraging effects produced by failure or poor growth of plantations, it seems well worthwhile to include the de-

termination of soil organic matter as a routine requirement in the future selection of planting sites. In the course of a few years, sufficient information should thus be accumulated to determine the full value and significance of soil organic matter content in different regions.

A problem which is likely to draw the attention of many foresters is the influence of soil organic matter upon the growth of trees planted in furrows. Deep furrowing removes the entire humus layer of soil and thus apparently deprives the seedlings during their early growth of the benefit derived from organic matter. However, a considerable portion of the organic matter is gradually washed into the furrows. Moreover, in a relatively short time, the spreading root systems utilize the water and nutrients retained in the humus layers of the surrounding undisturbed ground. Therefore, it does not seem quite justifiable to overlook the content of organic matter even when deep furrowing is planned.

The attention of the writers has been called to the exceptionally good growth obtained with pine seedlings planted in deep excavations along highways where as much as two feet of soil had been entirely removed. It seems that the explanation lies in the fertilizing effect of soluble salts and humus washed into these depressions by runoff. The absence of competing vegetation, protection from wind, and a favorable content of moisture are other contributing factors.

A few incidental observations in hilly regions have indicated that the organic matter content of cut-over soils is greater on northern than on southern exposures. It is probable that the influence of several site factors, such as light, temperature, and moisture, common to various topographical aspects, will be expressed by the data from soil organic matter determinations.

The determination of organic matter content may also serve as an index of soil depletion resulting from grazing, scraping of litter, or burning, and may be very useful in the management of woodlot soils.

SUMMARY

The content of soil organic matter was studied in relation to reforestation practice. Investigations were confined to central and northern Wisconsin, and involved four important conifers, *Pinus banksiana*, *P. resinosa*, *P. strobus*, and *Picea glauca.* A close relationship was found between the content of organic matter and that of total nitrogen, available phosphorus and available potash in outwash and pitted outwash sandy soils derived from granitic rocks. The study of plantations showed a pronounced increase in the rate of height growth of jack pine and red pine due to a higher content of organic matter. A general tendency for the increased survival of seedlings was observed on soils high in humus, but the correlation was not significant on the basis of the present observations.

Because the influence of organic matter within certain limits supplements the effect of mineral colloids, both factors were given consideration, and suitable standards are suggested as a guide in the selection of planting sites.

A technic of sampling forest soil was worked out and the Schollenberger's chromic acid titration method was adapted for use in forestry practice.

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THE AVAILABILITY OF REPLACEABLE POTASSIUM TO TOMATOES ON A SASSAFRAS SANDY LOAM[1]

Jackson B. Hester and F. A. Shelton[2]

IT IS known that a large amount of potassium is used in the production of a tomato crop. In certain sections of the country it has been customary for the growers to apply large amounts of high potash fertilizers before planting. It is a practice for some of them to mix the fertilizer in the row and allow it to be exposed to the elements for a period of several days before planting. If a good rain occurs between the time the fertilizer is applied and the plants are set, no injury is likely to occur to the transplants but, when there has been little or no rain, often much difficulty is experienced in obtaining a stand. While it is known that many of the soluble salts in mixed fertilizers will cause this trouble, one of the chief ones is muriate of potash. If potassium remains available to tomatoes in the replaceable state, high salt concentration in the soil can be avoided. A series of experiments were designed to give information upon the availability of replaceable potassium and potassium added to a soil from soluble salts.

PREPARATION OF POT CULTURES

For use in these experiments a virgin Sassafras sandy loam, analyzing 17% clay in the topsoil and 24% clay in the subsoil, was obtained from a woods near Moorestown, N. J., some of the chemical characteristics of which are shown in Table 1. A series of 2-gallon coffee-urn lining pots were prepared by tamping in 7,000 grams of subsoil (Fig. 1) comparable to the compactness under natural conditions and without any treatment of chemicals.

Table 1.—*Some chemical analyses of the Sassafras sandy loam soil used in the experiments.*

Horizon	pH in H_2O	pH in KCl	Organic matter, %	N, %	Replaceable M.E. per 1,000 grams of soil*		
					Ca	Mg	K
A..........	4.9	4.25	4.75	0.165	15.7	2.1	1.4
B..........	4.8	4.25	1.60	0.072	5.0	2.2	0.7

*Obtained by slowly leaching 50 grams of soil with 500 milliliter of N/2 ammonium acetate and chloride (pH 7.0).

Seven thousand grams of topsoil (the section under the heavily infiltrated organic layer) were limed with 40 grams of 200-mesh dolomitic limestone, a sufficient quantity to bring the pH value to approximately 6.1. Varying amounts of muriate of potash were likewise mixed with the topsoil before it was placed in the pot and, in this discussion, will be referred to as the odd-numbered pots or leached series. The soil was thoroughly moistened and allowed to stand a week and then

[1]Contribution from the Agricultural Research Department, Campbell Soup Company, Riverton, N. J. Received for publication March 29, 1940.
[2]Soil Technologist and Assistant, respectively.

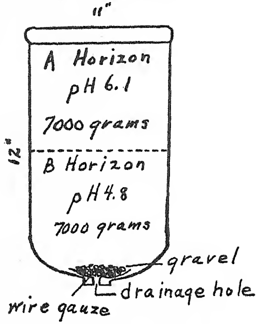

FIG. 1.—Giving the dimensions of the pot and the placement of the soil in the pot.

leached with rain water until approximately all of the chlorides were leached from the soil. This required the addition of sufficient water to give a leachate of 6 liters. A composite sample of this leachate was subjected to an analysis for chlorides, potassium, calcium, and magnesium.

The pots designated as the even-numbered or unleached series were then prepared the same as the odd-numbered pots with the exception of the potassium. This, in the muriate form and in amounts equal to that remaining in the odd-numbered pots after leaching, was then mixed with the topsoil in the even-numbered pots. In the odd-numbered pots the potassium was in the exchange complex of the colloid and in the even-numbered pots in the form of the chloride, except that certain exchange reactions between calcium and magnesium had no doubt taken place.

RESULTS OF LEACHING

Shown in Table 2 are the results of the analyses from the leaching experiment. It is well to remember that the high potassium contents represent very large applications of potassium, but not uncomparable to the concentrations in row applications of high potash fertilizer mixtures. In the low applications only relatively small amounts of potassium were leached from the soil (6 to 13% of the total added) but in the extreme applications as much as 48% of the potassium was leached. Later, it will be shown that a part of the potassium had collected in the subsoil. Practically all of the chlorides in the form of calcium and magnesium chloride, however, were leached out of the soil by the treatment even in the heaviest applications.

CROPPING PRACTICES

Finally, after the leached soils had come to optimum moisture content (14 to 16%) for crop growth, three vigorous, but small, Rutgers tomato plants were set in each pot. While the salt concentration of some of the pots was high, no difficulty was experienced in getting the plants to live. All plants were fertilized alike with ammonium nitrate and ammonium phosphate. The acidity in these chemicals was neutralized by the addition of lime and all chemicals were added in small portions at first. The pots were watered with rain water for optimum moisture but never sufficient to produce leaching. Finally, when the first crop was mature, the plants were harvested and yield records obtained. A second crop was planted immediately and fertilized similar to the first crop. Upon maturing, the plants were harvested and yield records obtained (Fig. 2).

TABLE 2.—*Results from the leaching procedure.*

Pot No.*	Percentage of added potassium leached	Milligram equivalents per pot		
		Potassium remaining of that added	Chlorides remaining	Calcium and magnesium leached
1	—	−2	0	6
2	—	0	8	0
3	6	63	1	54
4	—	63	71	0
5	13	117	0	115
6	—	117	125	0
7	27	195	0	215
8	—	195	203	0
9	36	340	10	322
10	—	340	348	0
11	47	558	0	564
12	—	558	566	0
13	48	1,067	56	997
14	—	1,067	1,067	0

*Odd-numbered pots leached until 6 liters of rain water passed through the soil. Even-numbered pots not leached.

The yield records for both crops were totalled and these results are shown in Fig. 3. These data bring out three significant facts. First, the yield of fruit of the leached series exceeded that of the unleached series at the higher applications of potassium, the yield increasing as the potassium increased; second, in the leached series the production of fruit was stimulated over vegetative growth where the higher amounts of potassium were present; and third, in the unleached series the highest quantity of soluble salts gave the lowest fruit formation in relation to vegetation; in other words, a less efficient plant.

AVAILABILITY OF POTASSIUM

The plant material from the two previously mentioned crops was analyzed for potassium and these data are summarized in Table 3.

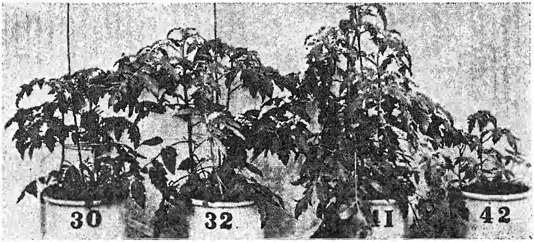

FIG. 2.—Showing the response of tomatoes to potash. Pot 30, no KCl; pot 32, 78 M.E. KCl; pot 41, 1,082 M.E. K clay; and pot 42, 1,082 M.E. KCl.

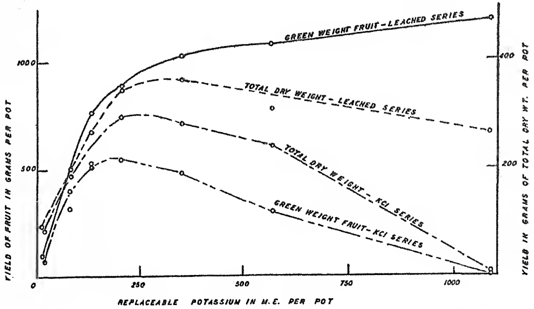

FIG. 3.—The influence of K clay and KCl upon the yield of tomatoes and vegetative growth.

These data bring out the fact that all of the replaceable potassium in the topsoil was absorbed by the plants in pots 1 and 2, but in no other case was all of the added and original replaceable potassium taken up by the plants. Through pot 6, the potassium absorbed from the unleached soil actually exceeded that of the leached soil, although the yield of pot 6 did not exceed that of pot 5; however, beginning with pots 7 and 8 the salt concentration was toxic and less potassium was absorbed from unleached than from leached pots.

TABLE 3.—*Availability of potassium to tomatoes.*

Pot No.	M.E. of K per pot		Yield in grams per pot		M.E. of K per pot		
	Total	Added and replaceable	Green weight of fruit	Total dry weight	Total absorbed	Second leaching	Replaceable left
1	309	13	100	94	17	0.2	-4
2	311	15	66	87	15	1.0	-1
3	374	78	404	205	37	0.5	40
4	374	78	333	192	63	2.1	13
5	428	132	760	273	97	0.6	34
6	428	132	524	206	113	2.7	16
7	506	210	888	348	172	1.0	37
8	506	210	546	299	162	1.3	47
9	651	355	1,016	363	198	1.3	156
10	651	355	497	283	132	13.9	209
11	869	573	1,073	311	163	1.0	409
12	869	573	298	241	325	56.6	191
13	1,378	1,082	1,180	263	207	2.9	872
14	1,378	1,082	0	11	9	185.0	888

After the second crop was removed, all pots were leached with rain water to obtain 2 liters of leachate on which an analysis was made to determine the amount of potassium present. Only very small quantities of potassium were leached from the odd-numbered pots, but larger quantities from the even-numbered pots. This, however, was not in proportion to the first leaching from the odd-numbered pots.

REPLACEABLE POTASSIUM REMAINING

When the absorbed and leached potassium were subtracted from the original added, there appeared to be large quantities of potassium remaining in the soil, beginning with pot 9 through pot 14. The topsoil was sampled and analyzed for replaceable potassium (Table 4). The original leached series showed very little replaceable potassium and even in the even-numbered pots only a portion of the added potassium could be accounted for. The previously leached samples were now leached with N/10 HNO_3 but very little potassium was removed; also, N/1 HNO_3 was allowed to stand on the soil overnight but very little more potassium came into solution and this was in about equal quantities all the way through the series. It was concluded, therefore, that the potassium remaining in the pot must be in the subsoil.

TABLE 4.—*Available potash in topsoil after second crop.*

Pot No.	Replaceable found*			M.E. of K per pot added	Yield of third crop		M.E. of K per pot removed by crop
	N/2 NH_4Cl and $NH_4C_2H_3O_2$	N/10 HNO_3	N/1 HNO_3		Grams of fruit	Grams dry weight	
1.....	6	1	1	0	0	11	1
2.....	4	0.4	1.6	0	0	18	2
3.....	7	1	2	13	91	70	20
4.....	7	1	2	13	62	72	27
5.....	8	1	2	26	83	68	27
6.....	8	1	1	26	42	61	33
7.....	9	1	2	39	0	65	47
8.....	10	1	2	39	46	65	42
9.....	10	1	2	52	14	81	58
10.....	13	1	2	52	378	87	73
11.....	8	1	2	65	322	83	73
12.....	78	3	2	65	90	73	80
13.....	8	1	2	0	166	51	20
14.....	369	5	2	0	27	13	22

*By leaching 50 grams of soil with 500 milliliters each treatment.

In order to see if this potassium could be returned to the topsoil, 100 rye seeds were planted and the rye allowed to grow during the summer months. Upon examination it was learned that the roots of the rye had completely permeated the topsoil but had not entered the subsoil at all (Fig. 4). It was concluded that the subsoil, being acid and carrying so little plant nutrients, had not been favorable for

root growth.[3] Upon examining the subsoil it was found that none of the roots of any of the previous crops had penetrated it.

In order to investigate the capillary action of the water in the pots on the movement of potassium, the rye was chopped up in the topsoil and a third tomato crop planted. Shortly after the crop was under way all of the plants in the odd-numbered pots began to show potassium deficiency symptoms and all but the last two of the even-numbered pots. Nitrate of potash in increasing amounts was added to the odd-numbered pots and muriate of potash and nitrate of soda (to equal the nitrogen in the nitrate of potash) were added to the even-numbered pots. The potassium-treated soils, except the high

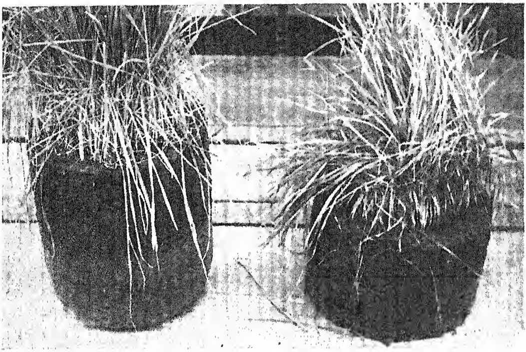

FIG. 4.—Showing that the topsoil (right) was thoroughly permeated with roots but that none had penetrated the acid subsoil (left). The two layers of soil separated when the rye was pulled upward.

salt content ones, produced good growth. The yield from this crop is shown in Table 4. These plants were analyzed for potassium and were found, except from soils of high salt concentration, to contain only the replaceable potassium found in the topsoil plus that added in fairly quantitative portions. This seems to point to the fact that if the subsoils are unfavorable for root penetration much of the potassium leached into them may be lost unless some crop tolerant to acid and unfavorable soil conditions is used to bring the potassium back. Further, since rye roots did not penetrate the subsoil in this experiment, it might be questioned whether on soils similar to this one potassium is not lost permanently unless the subsoil is limed or made more favorable for root penetration. This experiment indicates that

[3]HESTER, J. B., and SHELTON, F. A. The results of long-time fertilization and cropping practices upon the chemical and physical composition of Coastal Plain soils. Soil Sci. Soc. Amer. Proc., 2:201–205. 1937.

replaceable potassium is a good index of available potassium in Sassafras sandy loam soil and that very little weathering takes place in a period of 12 months.

PRACTICAL APPLICATIONS

In the light of this experiment it is interesting to examine field data obtained by the different methods of potash application. In a number of experiments conducted in various places it was found[4] that muriate of potash concentrated in large quantities under the row decreased the yield of tomatoes; whereas, larger quantities gave response when broadcast or used as sidedressings, as shown in Table 5. From a practical standpoint, if maximum yields are to be obtained from the use of muriate of potash, it may be advantageous to put it on sufficiently in advance of planting to permit the excessive salts to be leached from the soil or use it as sidedressings. This, of course, applies to large applications such as those often used on soil types similar to the one used in this experiment.

TABLE 5.—*Field results showing response of tomatoes to potash applied in different ways.**

Method of application	Lbs. per acre of K_2O applied	Yield, tons per acre	Lbs. per acre of K_2O absorbed by fruit
Mixed in row	0	7.38	49
Mixed in row	32	10.00	74
Mixed in row	64	9.27	65
Mixed in row	96	9.32	60
Mixed in row	128	7.00	54
Broadcast	200†	14.86	108
Sidedressed	250†	17.01	123

*Experiment designed to make potash the limiting factor, all plats carefully replicated.
†Used to show that under some conditions method of application is a greater factor than quantity of potash used in crop production.

SUMMARY

The leaching of potassium from a 6-inch column of topsoil of Sassafras sandy loam through 6 inches of subsoil is rather small on moderate applications of muriate of potash even with very severe leaching. Potassium in the acid subsoil was not readily drawn back into the topsoil in this experiment. Replaceable potassium in a Sassafras sandy loam was a good index of available potassium to tomatoes. Potassium in the replaceable form appeared to be a more efficient source for tomatoes than muriate of potash when it was supplied in large amounts near the plant roots.

[4]HESTER, J. B. Good, fair, or poor tomatoes from your soil. Bul. 2, Agr. Res. Dept., Campbell Soup Co. 1940.

IS TRIPPING NECESSARY FOR SEED SETTING IN ALFALFA?[1]

H. M. TYSDAL[2]

IN THE literature dealing with the necessity of tripping the alfalfa flower to set seed there is no unanimity of opinion. Brink and Cooper (2)[3] and Carlson (4) state that a large percentage of flowers set seed without tripping. On the other hand, Armstrong and White (1) and Piper, *et al.* (6) state that there can be practically no seed set without tripping.

The cause of tripping is equally confusing. Certain literature would lead the reader to believe that a very large amount of automatic tripping occurs, i.e., release of the staminal column by some inner force of the flower. Other workers apparently hold that wind and rain storms or bright sunshine may cause a lot of tripping, and still others hold that insects are the major agency causing tripping. Undoubtedly some of these workers believe that a combination of the above factors, or others, have a bearing upon the sum total of tripping which takes place, but there has been no clear-cut data to show the relative importance of each. Whether it is necessary for alfalfa flowers to trip to set seed under ordinary conditions is of great practical importance both from the standpoint of investigational work and recommendations for optimum seed production.

Tripping may be defined as the release of the staminal column from the keel of the flower. The staminal column includes the style, stigma, and part of the ovary enclosed or surrounded by the 10 stamens and diadelphous filaments. This release must take place when the flower is in a turgid condition and thus it is accompanied by an explosive force as though a spring under tension is released.

During the past three years a considerable amount of work has been done in Nebraska on this subject by L. A. Clark. His work, as yet unpublished, along with other observations made by the writer, led to the study which is herein reported. The present paper presents the results of studies at the Scotts Bluff alfalfa breeding nursery and of a cooperative survey made in several of the seed-producing areas of the United States during the season of 1939.

The data given herein are reported primarily for the purpose of focusing attention on the possible importance of tripping as related to seed production in alfalfa. It is hoped the discussion will stimulate observations on this phase of the problem since, if these observations

[1]Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Department of Agronomy, Nebraska Agricultural Experiment Station, cooperating. Published with the approval of the Director of the Nebraska Agricultural Experiment Station, Lincoln, Nebr., as Journal Series Paper No. 251. Also presented at the annual meeting of the American Society of Agronomy held in New Orleans, La., November 24, 1939. Received for publication April 15, 1940.

[2]Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. The author is greatly indebted to H. L. Westover, Senior Agronomist, Division of Forage Crops and Diseases, for suggestions and for making it possible to have cooperative observations made in several different areas of the country during the same season.

[3]Figures in parenthesis refer to "Literature Cited", p. 585.

hold true in most seed-producing areas in average seasons, it would help materially to explain some of the alfalfa seed problems encountered in recent years.

METHODS

A plan was devised under which five sets of data were obtained in each field or under each set of conditions. In each case four sets of racemes were tagged with different colored tags so they could be easily distinguished. In the first set the tripped flowers were removed from the marked racemes so that only the untripped flowers were allowed to proceed to the point where they either set pods or fell from the raceme. In the second set the flowers were allowed to develop normally and the amount of tripping that occurred was recorded. In the third group all of the flowers were tripped by hand either by introducing foreign pollen or by tripping the stigma onto its own pollen. Since there is a great difference in the percentage of pods formed, depending upon whether self or foreign pollen is used, the method employed will be indicated in each case.

The fourth group of flowers were bagged with fine nainsook muslin bags. In all of these groups the flowers which were tagged were in full bloom, untripped, and as nearly the same age as possible. Approximately 100 or more flowers were included in each set for each condition. Observations were made at sufficiently close intervals to determine whether the flower had been tripped. Since a flower which has been tripped may start wilting almost immediately, and within 2 to 4 hours have the standard petal wrapped tightly around the staminal column, it was often necessary to unwrap the standard petal to determine if tripping had actually taken place as at this stage "wilting" and "tripping" are easily confused. Ordinarily, when the observer becomes skilled in detecting tripped flowers, observations of the marked racemes morning, noon, and evening will provide accurate results.

The fifth set of observations had as their purpose the determining of the amount of automatic tripping and the amount of insect activity. This was done by continuous daylight observation of a group of flowers on one or two plants which could be kept under the eye of the observer at all times. The number of flowers which were tripped and the manner of tripping were recorded, as well as the total number of flowers visited by all insects. The total number of full flowers under observation was recorded, and the time recorded at 15- or 30-minute intervals so that later the data could be computed relative to the time of day and number of visitations per 100 flowers under observation per hour. Temperatures, weather conditions, and the amount of seed set in the field were noted.

During the summer of 1939 sets were placed on alfalfa plots or commercial fields in the following places: Ohio Agricultural Experiment Station, Columbus, Ohio; Agricultural Experiment Station, Lincoln, Nebr.; Agricultural Experiment Station, Manhattan, Kans.; Scotts Bluff Field Station, Mitchell, Nebr.; Riverton, Wyo.; Blackfoot, Idaho; Agricultural Experiment Station, Aberdeen, Idaho; Eastern Oregon Livestock Branch Experiment Station, Union, Oregon; and the Agricultural Experiment Station, Logan, Utah. The writer is indebted to T. Jackson Smith, Columbus, Ohio; C. O. Grandfield, Manhattan, Kans.; John L. Toevs, Aberdeen, Idaho; Messrs. Minnick and Perry, Union, Oregon; and J. W. Carlson, Logan, Utah, for taking the observations and for consenting to the use of their data in this paper. The interpretation of the data, however, is that of the author and does not necessarily reflect the opinions of the cooperators.

RESULTS

Table 1 gives the results of the four treatments in the different areas. The percentage of flowers tripped was found by averaging the results from the set in which the tripped flowers were removed, together with the results from the set in which the flowers were allowed to develop normally but in which a record was kept of the amount of tripping. Three divisions are made in Table 1 according to the estimated seed-yielding capacity of the fields under observation. For example, three fields were chosen within a few miles of each other near Riverton, Wyo., one of them setting seed very well (estimated at 500 pounds per acre, subsequently found to yield 560 pounds per acre); a second which was intermediate in seed production, estimated at 250 pounds per acre; and a third which was setting very little seed, estimated at approximately 60 pounds per acre. Thus, in this area, is represented a poor, medium, and good field. The fields are numbered in Table 1 for identification purposes.

TABLE 1.—*Percentage of flowers naturally tripped in different areas of the country and percentage forming pods under four different treatments.*

Place	Station or farm No.	Percentage flowers tripped naturally	Percentage flowers forming pods			
			Without tripping	Naturally	Artificially tripped	Under bags
Fields with Poor Seed Setting						
Ohio	1	38	2	20	67	5
Nebraska	2	37	3	24	27*	3
Wyoming	5	33	6	23	76	4
Idaho	8	14	2	7	91	4
Idaho	9	36	0	5	77	1
Oregon	11	11	2	14	58	1
Utah	13	25	2	12	75	3
Av.	—	28	2	15	74	3
Fields with Medium Seed Setting						
Nebraska	3	19	1	10	89	5
Kansas	4	44	1	24	41*	4
Wyoming	6	33	6	20	81	3
Av.	—	32	3	18	85	4
Fields with Good Seed Setting						
Wyoming	7	63	0	47	73	1
Idaho	10	44	0	25	73	5
Oregon	12	41	0	33	81	1
Av.	—	49	0	35	76	2

*Self-pollinated, not used in averages; all others were cross-pollinated.

The average percentage of the flowers tripped by natural causes, whether by wind, insects, or automatically, shows a rather wide variation in different fields whether they are good or poor, but in

general the poor fields have less tripping than the medium or good fields. The differences have not been statistically analyzed, but it is clear from the data, and still clearer from field observations, that the poor fields did not have the large amount of tripping that was found in the good fields. A correlation of $.8167 \pm .0623$ was found between percentage of flowers tripped under natural conditions and percentage of flowers forming pods under natural conditions, although some variation between different fields is evident.

Columns 4 and 7 in Table 1 show that under average conditions tripping is necessary for seed setting. Thus, although tripping may not insure seed production, at least seed will not be produced to any great extent without tripping. All the fields under observation, involving some seven different widely scattered areas in the United States, and a large number of observations for each condition, present no single exception to a very low percentage of pod set when the tripped flowers are removed. The highest percentage found was 6 and in most cases it was less.

Column 7 in Table 1 shows the percentage of flowers forming pods when the full untripped flowers were enclosed in nainsook muslin bags. Obviously no large insects visit the flowers so enclosed. The percentage of the flowers forming pods under these conditions checks very closely with the amount of pod setting when the tripped flowers are removed as shown in column 4. To determine whether the muslin bag disturbed seed setting, a test was run where all of the flowers enclosed in the bag were artifically tripped before covering, a group of racemes from the same plant were enclosed in other bags in the usual manner at the same time, and a third group was artifically tripped and left to develop without being covered. It was found that 3.6% of the flowers which were enclosed in the bag but not tripped developed pods, 85.7% of the flowers which were enclosed in the bag but tripped before covering produced pods, and 78.5% of the flowers which were artificially tripped and allowed to develop on the outside produced pods. This indicated that the bag in itself apparently did not have a harmful effect on pod setting.

Column 5 in Table 1 gives the average percentage of flowers forming pods under natural conditions. The good fields averaged considerably higher in this respect than the poor or medium good fields. It should be pointed out that these data are relative rather than exact for any given field, the chief reason being that when the racemes were tagged and visited rather frequently by the observer less insect activity occurred on the plants under observation. For example, actual counts were made in fields 2, 8, and 10 on the number of flowers producing pods in the field as a whole at about the time the sets were being observed. This was done by taking a representative group of racemes on which the pods were about the same age as those on the observed plants, and counting by the bracts the number of flowers originally on the racemes and then counting the number of pods actually set. When this was done, it was found that in field 2 actually 44% of the flowers set pods compared to 24% reported in Table 1; that in field 8, 10% of the flowers had set pods, whereas Table 1 indicates 7%; while in field 10, 54% of the flowers were setting pods,

compared to 25% as found on the plants under observation. The same explanation may be given for the observations on the actual amount of tripping occurring in the field and the amount found on the plants under observation as given in column 3. Thus, the general observations in the field, taken very carefully, are important in the final interpretation.

The results to which this explanation does not apply are those in which the condition of the flower was determined by controlled means, as in the case of the percentage of flowers forming pods without tripping and those which were artificially tripped, and perhaps to a lesser extent those enclosed within the bag. The results of these three treatments are also much less variable than the others just mentioned.

The results from artificial tripping are of particular interest. In this experiment a group of racemes was used on the same plants on which the other observations were being made, all the flowers being tripped by hand, and usually cross-pollinated by gathering foreign pollen on a toothpick and then tripping the flower with this toothpick in such a way that the stigma snapped onto the foreign pollen. No attempt was made to remove the flower's own pollen, which was also present, but previous experiments had indicated that the foreign pollen is the effective agent from 80 to 98% of the time. When no foreign pollen was introduced the flowers were said to have been self-pollinated, although a few stray pollen grains may have adhered to the standard or other parts of the flower.

With two exceptions, the results reported for artificial tripping in Table 1 are from cross-pollinations. In practically all cases, whether in Ohio or Oregon, the alfalfa set a very high percentage of pods when cross-pollinated. When it is considered that if 50% of the pods set seed in the ordinary alfalfa field a good crop of seed is obtained, the high percentage of setting with artificial tripping can readily be appreciated. The averages for the poor, medium, and good fields do not show any significant trends, as they are all quite high.

The two exceptions, those which were self-pollinated in Nebraska and Kansas, show a very much lower percentage forming pods. That this may be considered a general condition in alfalfa is shown by the results given in Table 2.

In the first part of Table 2 is given the average percentage of pods set for a number of representative plants when selfed and cross-pollinated. In all tests the percentage of flowers forming pods for the selfed material is much lower than that for the crossed. On the average 92% more pods are set from the crossed than from the selfed flowers.

The second part of Table 2 gives the results of a similar experiment on different individual plants. Plant 16–42 set almost as many pods when self-pollinated as when cross-pollinated; plant 31–43, on the other hand, was almost self-sterile, setting only 10% of pods as compared to 97% when cross-pollinated. A sufficiently complete sampling of the population has not been made to estimate what proportion of the average commercial alfalfa population is largely self-fertile. Observations during the course of the breeding program, however, would indicate that relatively few plants are as self-sterile as No.

TABLE 2.—*Percentage of flowers forming pods when all flowers are tripped and self-pollinated compared to all flowers tripped and cross-pollinated.*

Place	Percentage of flowers forming pods	
	Selfed	Crossed
Average of Several Plants		
Ohio	32	67
Nebraska, 1938	16	50
Nebraska, 1939	60	89
Av.	36	69
%	100	192
Variability of Individual Plants		
Nebraska, 1939:		
Plant No. 16–46	93	100
31–41	70	100
20–51	58	97
31–43	10	97

31–43, but many indications (3) point to a selective fertilization in practically all plants if the foreign pollen is available.

In addition to the higher percentage of pods being formed upon cross-pollination, data presented in Table 3 indicate that a larger number of seeds are formed per pod from the cross-pollinated than from the self-pollinated flowers. As an average of three separate readings, one at Ohio and two at the Scotts Bluff alfalfa breeding nursery, one in 1938 and the other in 1939, the pods produced from self-pollination contained 2.44 seeds each, while those from the cross-pollination contained 3.80 seeds each, an increase of 56%. Considering both the percentage of flowers forming pods and the number of seeds per pod, the cross-pollinated flowers produced almost exactly three times as much seed as the self-pollinated.

An important consideration from the standpoint of principles involved, is the variability in seed setting during different parts of the

TABLE 3.—*Number of seeds per pod when self-pollinated as compared to seeds from cross-pollinated flowers.*

Place	Number of seeds per pod	
	Selfed	Crossed
Columbus, Ohio, 1939	2.15	2.81
Scotts Bluff, Nebr., 1938	2.00	2.47
Scotts Bluff, Nebr., 1939	3.16	6.11
Av.	2.44	3.80
%	100	156

same season. Table 4 gives the amount of natural tripping taking place at different times in the same season at Columbus, Ohio, and at Scotts Bluff, Nebr., and also the percentage of flowers forming pods during the same period. It is evident that during a short period of one or two weeks a very great difference in response is obtained. At Scotts Bluff, in a set on August 8, no tripping was found on the plants under observation nor were any pods set. In a set on August 21, however, 61% of the flowers were naturally tripped and 28% of them set pods. The first three days after the set of August 8 the mean maximum temperature was 71° F and the mean minimum 50°. The mean maximum relative humidity was 98% and the mean minimum 44%. Similar figures for the 3-day period following the set of August 21 were mean maximum 89° F, mean minimum 53°, mean maximum relative humidity 98%, and mean minimum 22%. Field observations often show as much variability from day to day as shown in Table 4

TABLE 4.—*Variability in percentage of flowers tripped and percentage forming pods under natural conditions at different times of the season.*

Place	Date	Percentage flowers	
		Tripping	Forming pods
Columbus, Ohio	Aug. 1–15	25	16
	Sept. 6–20	64	30
Scotts Bluff, Nebr.	July 27	13	7
	Aug. 8	0	0
	Aug. 21	61	28

from week to week. In fact it has been one of the interesting results to observe how remarkably sensitive bees, and particularly *Megachile*, are to weather conditions. When the weather was at all cold or cloudy or rainy a very sudden drop or complete cessation of insect activity was noted. This may be one of the keys explaining why alfalfa seed setting is so sensitive to weather conditions. Table 4 again gives an indication of the close relation between tripping and pod setting, the rank in percentage of tripping being the same as the rank in percentage of flowers forming pods.

Time and temperature records were taken when continuous observations were made on insect visitation to alfalfa flowers at Scotts Bluff in 1938 and Lincoln in 1939. The total number of flowers visited and the total number of flowers tripped were recorded, as well as the approximate number of flowers under observation. These records are tabulated on the basis of time of day and temperature in Table 5. Table 6 gives the comparable data for one day, August 24, 1938. Table 6 also gives the visitations to alfalfa flowers by the *Megachile* species as distinguished from the total number of flowers visited by all insects.

In all tables the averages are in terms of number of flowers visited or tripped per hour per hundred flowers under observation. This will be referred to as "percentage" of flowers visited or tripped per hour,

TABLE 5.—*Number of insect visitations to a known number of alfalfa flowers and number of alfalfa flowers tripped at different times of the day and at different temperatures, Scotts Bluff, Nebr., Aug. 24 to Sept. 6, 1938.**

Time of day and temperature	Total No. flowers visited	Percentage of flowers visited per hour	Total No. flowers tripped	Percentage of flowers tripped per hour
8– 9 a.m....	72	4.8	6	0.4
9–10 a.m....	67	4.5	28	1.9
10–11 a.m....	160	10.7	30	2.1
11–12 a.m....	82	5.5	31	2.1
12– 1 p.m....	97	6.7	49	3.3
1– 2 p.m....	353	23.6	67	4.5
2– 3 p.m....	430	28.7	81	5.4
3– 4 p.m....	462	30.8	84	5.7
4– 5 p.m....	100	6.7	0	0.0
70° F........	355	9.6	50	0.9
75° F........	1,426	15.9	149	1.7
80° F........	1,658	18.6	358	5.1
85° F........	2,897	34.3	649	7.4

*The results are averages for a 7-day period.

TABLE 6.—*Number of insect visitations to a known number of alfalfa flowers and number of alfalfa flowers tripped at different times of the day and at different temperatures, Scotts Bluff, Nebr., Aug. 24, 1938.*

Time of day	Total No. of flowers visited	Percentage of flowers visited per hour	Total No. of flowers tripped	Percentage of flowers tripped per hour	Percentage of flowers visited by *Megachile* per hour	Temperature, ° F
8– 9 a.m.....	72	4.8	6	0.4	0.7	68°
9–10 a.m.....	67	4.5	28	1.9	2.0	72°
10–11 a.m.....	108	7.2	28	1.9	2.0	75°
11–12 a.m.....	82	5.5	31	2.1	2.3	75°
12– 1 p.m.....	97	6.7	49	3.3	3.8	80°
1– 2 p.m.....	238	15.8	134	8.9	11.1	81°
2– 3 p.m.....	251	16.7	106	7.1	8.8	82°
3– 4 p.m.....	264	17.6	78	5.2	6.4	83°
4– 5 p.m.....	12	0.8	0	0.0	0.0	82°

as the case may be, but it should be understood that it is calculated on the basis of the number of full flowers remaining untripped each hour. Thus, both time and number of flowers are kept constant, making it possible to compare from day to day and at different temperatures. There were actually about 1,500 flowers under observation during this test.

The data for the one day, August 24, which is taken because complete records were made from morning to evening and because it shows several typical tendencies, are graphically presented in Fig. 1. This figure shows the total insect visitations, *Megachile* visitations, and the number of flowers tripped at different periods of the day, reported in per cent. The notes made in the record book indicate that the

morning was rather cloudy but that the sun came out bright and warm just before 1:00 o'clock and remained out during the afternoon. The insect activity as represented by the number of flowers visited per hundred per hour shows a very decided increase during the 1:00 to 2:00 o'clock period as compared with the 12:00 to 1:00 o'clock period. Similarly, the activity of the *Megachile* species shows an increase at this time of day. As can be noted from the graph, the amount of tripping also increased very much at this time. Perhaps the most important feature of the graph is the very close correlation between the *Megachile* visitation and the number of flowers tripped. If, as has been indicated, the *Megachile* species is the most important in causing tripping in this section, it is to be expected that there would be a close correlation between *Megachile* activity and tripping.

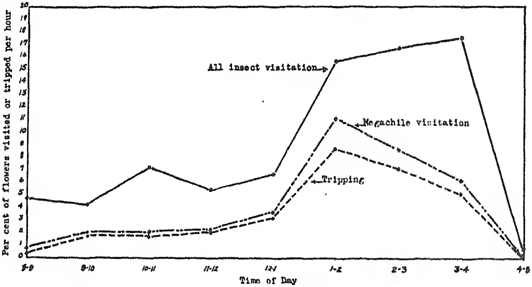

FIG. 1.—Tripping and insect visitation as related to time of day, Scotts Bluff, Nebr., Aug. 24, 1938.

It will also be observed that the insect activity is greatest during the middle of the afternoon, and it is also during this period, from 1:00 to 4:00 o'clock, that the greatest number of flowers are tripped. As a rule there is very little *Megachile* activity in the late afternoon, and this is correlated with practically no tripping from about 4:00 o'clock in the afternoon to 8:00 o'clock the next morning during this season in western Nebraska. In Lincoln, however, there is some continued activity from 4:00 to 5:00 o'clock in the afternoon.

Temperatures apparently play a very important role in insect activity and alfalfa tripping, as shown in Tables 5 and 6 and in Fig. 2. In western Nebraska the insect activity and number of flowers tripped increased with each successive 5° raise in temperature from 70° to 85° F, showing that the warmer the day, the greater the tripping. Evidently the threshold value for beneficial insect activity is in the neighborhood of 65° F under these conditions, although this might vary somewhat with species and with environmental conditions.

In 1939 observations were made at Lincoln on insect visitations to alfalfa flowers and tripping. Table 7 gives the result of observations taken at intervals during the period of August 18 to 22, 1939, and Table 8 gives the results of continuous observations made on total tripping occurring in the field during the period of September 7 to 15, 1939. During the latter period, very great activity of insects was recorded and a very high percentage of tripping noted. Over 85% of all flowers under observation during this period were tripped. As can be seen from Table 8. there is again a correlation between the amount of tripping and temperature, there being a gradual increase in the number of flowers tripped per hundred per hour from 70° to 100° F. In the Lincoln data for the period of August 18 to 22, a drop in the insect activity and tripping is noted at 85° F. This is attributed to inconsistency of the data, rather than an actual decrease in activity at this temperature.

Table 8 also shows the greatest amount of tripping to be during the period of 1:00 to 4:00 p.m., although a considerable amount of tripping occurred earlier in the day during the warm period. The relationship between insect visitation and tripping may of course be entirely altered according to the insect population present. For example, in counts where there was a high honey bee population there was as high as 90% of the flowers visited per hour but there was less than 2% of the flowers tripped.

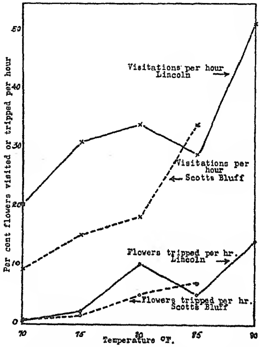

FIG. 2.—Tripping and insect visitation to alfalfa flowers as related to temperature, Scotts Bluff, Nebr., Aug. 24 to Sept. 6, 1938, and Lincoln, Nebr., Aug. 18 to 22, 1939.

TABLE 7.—*Number of insect visitations to a known number of alfalfa flowers and number of alfalfa flowers tripped at different temperatures, Lincoln, Nebr., Aug. 18–22, 1939.*

Temperature, ° F	Total No. of flowers visited	Percentage of flowers visited per hour	Total No. of flowers tripped	Percentage of flowers tripped per hour
70°	154	20.5	4	0.5
75°	233	31.2	15	2.1
80°	257	34.3	79	10.5
85°	348	29.5	66	5.3
90°	390	51.9	107	14.3

The question, therefore, of what causes tripping in alfalfa may be answered, at least for certain field conditions, although these results do not preclude the possibility of automatic tripping taking place

TABLE 8.—*Total number of alfalfa flowers tripped during continuous daytime observations of marked racemes at different times of the day and at different temperatures, Lincoln, Nebr., Sept. 7–15, 1939.*

Time of day and temperature	Total No. flowers tripped	Per cent flowers tripped per hour
8– 9 a.m.	6	11.4
9–10 a.m.	10	12.9
10–11 a.m.	8	11.3
11–12 a.m.	16	14.6
12– 1 p.m.	12	18.2
1– 2 p.m.	17	25.5
2– 3 p.m.	16	30.0
3– 4 p.m.	11	35.8
4– 5 p.m.	4	13.4
70° F.	19	6.9
75° F.	23	17.2
80° F.	52	17.9
85° F.	79	21.5
90° F.	94	18.9
95° F.	243	19.1
100° F.	144	37.1

under different conditions. Many of these results have been obtained by tagging certain racemes, which were closely and continuously observed during the daylight hours for any change that might occur. This is more difficult to do than may appear, however, as it is difficult to observe each flower, particularly during windy weather. The writer can say from experience that it is almost impossible to detect all of the insect activity actually in progress when a high wind is vigorously waving the 8 or 10 marked racemes of a plant. It is believed that for this reason a considerable amount of insect activity has been overlooked in the past. It is also believed that this may account for the unusually high reading for automatic tripping recorded at Lincoln in Table 9. The readings at Lincoln were made in very unusual weather. The maximum temperature during the period reached 105° F and the average maximum from September 6 to September 14, during which time readings were made, was 95° F. The average maximum wind velocity for the same period was 23 miles per hour, the highest velocity being 28 miles, and the lowest 16 miles. Twenty-six hundredths of an inch of rain had fallen in the preceding 3-week period, and previous to that time precipitation was scanty. Thus very dry, hot, windy conditions pervailed, which, according to some observers, would be ideal for seed setting provided there was sufficient moisture to allow continued development of the plant. Since the plants under observation were space-planted, sufficient moisture was present to allow them to continue growth. As a matter of fact these conditions apparently were beneficial for seed production because some of the plants which were left for seed produced a good seed crop, many of them at the rate of about 10 bushels per acre.

In making the observations it was considered desirable to allow the plants as much freedom as would obtain under natural conditions.

Approximately 10 racemes were tagged on each plant and a note made as to the number of full flowers on each raceme. The wilted, tripped, or undeveloped flowers were removed, records being made of each insect visitation, each time the insect tripped a flower, or each time a flower was tripped without the aid of an insect. The latter tripping might have been caused by brushing against other stems blown by the wind, or by the opening of the keel due to dehydration or high temperatures. It has been demonstrated under experimental conditions that high temperatures of about 140° to 150° F will cause automatic tripping, and that the addition of a very small drop of alcohol to the clasp of the keel will cause it to open. Regardless of the manner in which the tripping occurred, when not due to insects, it was listed in Table 9 as automatic.

TABLE 9.—*Cause of tripping of alfalfa flowers as determined by field observations of marked racemes.*

Place	No. of flowers under observation	Percentage of flowers tripped		
		By insects	Unknown	Automatically
Nebr. (Lincoln).......	739	44	12	29
Nebr. (Scotts Bluff)...	260	26	8	1
Wyoming...........	55	22	0	0
Idaho..............	95	4	0	2

One other statement should be made relative to the data from Lincoln. In one test, the stems having marked racemes were tied to stakes so that they could not be blown by the wind, thus permitting careful and continuous observation of the flowers. Not a single flower tripped automatically all day. The data from Lincoln are therefore included in Table 9 with reservations, but despite all of these considerations it is believed they are of some value to show that even under these unusual conditions the amount of automatic tripping recorded is not sufficient to produce a good seed crop.

The data from Scotts Bluff, Nebr., Wyoming, and Idaho are consistent in showing very little or no automatic tripping, even under conditions which in Wyoming produced 560 pounds of seed per acre. The actual percentage of tripping indicated in Table 9 is relative but not truly indicative of the tripping in the general field, as again it was taken when the observer was immediately adjacent to the plant and it was very evident that the wild bees did not work as well under close observation as on plants farther away.

Table 10 gives a brief summary of the actual agencies causing tripping.[4] By far the largest number of visitations to alfalfa flowers in most seed-producing areas are by honey bees (*Apis* sp.). The leaf cutter bees, often called ground bees or solitary bees, all of which are species of *Megachile*, probably are second in number in Nebraska,

[4]Acknowledgment is made to Prof. Don B. Whelan of the Department of Entomology, University of Nebraska, for kindly making the identification of insects observed working on alfalfa.

and other insects, such as bumble bees, wasps, etc., are present in smaller numbers. In the western states, including Wyoming, Idaho, and possibly Utah and Oregon, the alkali bees or ground bees, which are species of *Nomia*, chiefly *Nomia melandri*, appear to be the most common alfalfa pollinators. In eastern states bumble bees appear to be more important.

TABLE 10.—*Amount of tripping of alfalfa flowers caused by various insects as determined by field observations of marked plants.*

Place and year	No. of flowers visited by			Percentage of flowers tripped by		
	Honey bee	*Megachile* and *Nomia* sp.	Misc. insects	Honey bee	*Megachile* and *Nomia* sp.	Misc. insects
Ohio, 1939..........	1,401	79	30	2.7	94	87
Nebr., 1938.........	3,442	635	331	0.3	83	11
Nebr., 1939.........	528	45	325	0.6	91	6
Wyoming, 1939......	1,282	39	0	1.7	82	0
Total or av........	6,653	798	686	1.1	84	12
Total No. of flowers tripped.........	—	—	—	76	674	82

In these tests the honey bee was not an effective tripper of alfalfa flowers. Out of 6,653 alfalfa flowers visited by honey bees, a total of 76 or 1.1% were tripped. On the other hand, during the same period 798 flowers were visited by leaf cutter bees and 674 or 84% were tripped. A total of 686 flowers were visited by a number of other insects, including bumble bees (*Bombus* sp.), wasps, moths, and others, and of these 82 or 12% were tripped. Most of these were tripped by bumble bees, which apparently, however, vary in effectiveness, tripping from 38 to 80% of the flowers visited. During these observations the *Megachile* or *Nomia* sp., which are remarkably adapted for producing cross-pollination in alfalfa, tripped more than four times as many flowers as all the rest of the insects combined.

One factor which is not clearly brought out in Table 9 is the effect of constant visits of honey bees to the same flower. When the bees are extremely numerous the same flower may be visited a great many times, and in this way a higher percentage of flowers are tripped than shown in Table 10. Actual counts have shown honey bees to trip as much as 12% of the flowers of a given raceme during the course of two or three days. This would indicate that honey bees in abundance might be beneficial for seed setting. It has also been observed that certain honey bees are much more apt to trip alfalfa flowers than others, thus indicating rather wide differences among individuals in the same species. Plants also differ in ease of tripping.

The possibility of antagonism or competition between various insects should perhaps be given consideration in future investigations. Thus, for example, an abundance of honey bees might tend to dis-

courage the activity of the *Megachile* or *Nomia* sp. which might otherwise be present. Whether there is any such competition is not known, but even if there is no direct antagonism, it is evident that if one species is present in such abundance that it tends to rob the nectar from another more beneficial species it would be to the disadvantage of the seed grower.

DISCUSSION

The most effective pollinators in this study have been the *Megachile* and *Nomia* bees, several species of which have been observed working on alfalfa. Other conditions being favorable, it would appear that one of the most effective means of insuring a seed crop of alfalfa would be a supply of these small, relatively harmless, hard-working insects. It should, therefore, be sound agronomic practice to encourage their presence in an alfalfa seed field. The writer has talked with alfalfa seed growers who have plowed through a large colony of these bees, which often make their home in the ground, and in some instances it has been known that such practices have destroyed the entire colony, or at least caused it to move. It would seem to be worth while to investigate the possibilities of propagating such bees which are effective tripping agents. The presence or absence of tripping insects in an alfalfa field may eventually prove to be a reliable criterion of seed setting possibilities, providing their sensitivity to weather conditions is also taken into consideration.

The results presented in this paper point to the conclusion that, in general, alfalfa flowers must be tripped to produce seed, and that ordinarily there is not sufficient automatic tripping to produce satisfactory seed crops. It would not be true to say that all seed conditions have been encountered in these investigations, and thus it is possible that under certain conditions a higher percentage of flowers might produce seed without tripping, or a higher percentage of automatic tripping might occur than was observed; however, it would seem that such conditions are comparatively rare. Strengthening this conclusion is the fact that all reports in the literature indicate a high percentage of natural crossing in alfalfa, and our own results show from 60 to 90% natural crossing under Scotts Bluff conditions, and crossing would appear to be difficult to explain without tripping. Sudden rain storms which have been observed to cause considerable tripping would not appear to be advantageous for cross pollination.

It should be noted that autogamous plants have been found in certain breeding programs. Kirk and White (5) have reported such results and at least one plant which sets seed without tripping has been isolated in the Nebraska alfalfa breeding program. Some of these plants apparently set seed without tripping or are self-tripping. While these possibilities should be thoroughly investigated, it is difficult to see how continued vigor of growth could be maintained if the plants were entirely self-fertilized. It may be possible, however, to combine a certain amount of self-fertility with sufficient natural crossing to increase the general seed setting of the strain.

Tripping by mechanical means does not at present appear to be feasible for two chief reasons. In the first place, new alfalfa flowers

are developing all the time, since alfalfa has an indeterminant inflorescence, and they are in prime condition for fertilization only from one to three days. To trip them at the right time would necessitate going over the field a large number of times. In the second place, unless the machine were constructed so that a large amount of crossing occurred, and this would seem difficult to accomplish, the self-fertilization resulting from such tripping would cause less seed per flower and lower vigor of growth of the resulting progeny than would result if the same flowers were cross-pollinated.

A rather significant situation appears when the alfalfa seed areas are studied from the standpoint of reliability in seed production. It appears that the most consistent seed production has been in the pioneer areas. Some areas were good seed producers and then, without apparent reason, seed failures became common, although in occasional years a good seed crop was obtained (4). On the other hand, during these same years, new areas brought under production produced rather consistently good seed crops. Examples of these newer areas are found in isolated districts of western Utah, in Oregon, and in the newly developed irrigation project at Riverton, Wyoming. The author can state that he saw more colonies of the *Nomia* species in the Wyoming areas than in any other seed production area he has visited.

Entomologists who have observed the alfalfa pollinating insect population in Nebraska for many years unhesitatingly state that there are fewer colonies of *Nomia* species and fewer of *Megachile* species than formerly. It is possible that cultivation and settlement has disturbed the wild bees and thus reduced their number. Hence, it is suggested that a decrease in the population of these beneficial insects, together with a possible increase in harmful insects, may be an explanation for the uncertainty in alfalfa seed production in formerly good seed-producing areas.

One criticism made of the dependence upon insects for seed setting in alfalfa is that in certain years very good seed production is obtained in areas which have not been producing good seed crops. This cannot be explained from the data at hand, but reference can be made to very great differences in seed setting of red clover from year to year in which crop it has been admitted insect visitation is a necessity. Observations have indicated a great difference in the beneficial insect population in a given area from year to year. Apparently, favorable or unfavorable environmental conditions can cause a very rapid change in the insect population.

Despite emphasis placed on tripping, it should be remembered that many other factors affect alfalfa seed production. It is only too true that under some conditions all the flowers could be tripped and cross-pollinated and still set very little seed. Under other conditions, such as stimulation of the vegetative phase of growth as compared to the reproductive phase, or presence of harmful insects, such as *Lygus*, very few flowers may be produced. Apparently the balance which is necessary for reproductive development in alfalfa can very easily be tipped toward the vegetative phase and no doubt that is why alfalfa is such a high forage producer. There are many examples, however, in seed-producing areas where everything seems to be

favorable for a seed crop and yet the crop is very poor. Under these conditions a lack of tripping may be the determining factor.

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PIPER, C. V., EVANS, MORGAN W., McKEE, ROLAND, and MORSE, W. J. Alfalfa seed production; pollination studies. U. S. D. A. Bul. 75. 1914.

are developing all the time, since alfalfa has an indeterminant inflorescence, and they are in prime condition for fertilization only from one to three days. To trip them at the right time would necessitate going over the field a large number of times. In the second place, unless the machine were constructed so that a large amount of crossing occurred, and this would seem difficult to accomplish, the self-fertilization resulting from such tripping would cause less seed per flower and lower vigor of growth of the resulting progeny than would result if the same flowers were cross-pollinated.

A rather significant situation appears when the alfalfa seed areas are studied from the standpoint of reliability in seed production. It appears that the most consistent seed production has been in the pioneer areas. Some areas were good seed producers and then, without apparent reason, seed failures became common, although in occasional years a good seed crop was obtained (4). On the other hand, during these same years, new areas brought under production produced rather consistently good seed crops. Examples of these newer areas are found in isolated districts of western Utah, in Oregon, and in the newly developed irrigation project at Riverton, Wyoming. The author can state that he saw more colonies of the *Nomia* species in the Wyoming areas than in any other seed production area he has visited.

Entomologists who have observed the alfalfa pollinating insect population in Nebraska for many years unhesitatingly state that there are fewer colonies of *Nomia* species and fewer of *Megachile* species than formerly. It is possible that cultivation and settlement has disturbed the wild bees and thus reduced their number. Hence, it is suggested that a decrease in the population of these beneficial insects, together with a possible increase in harmful insects, may be an explanation for the uncertainty in alfalfa seed production in formerly good seed-producing areas.

One criticism made of the dependence upon insects for seed setting in alfalfa is that in certain years very good seed production is obtained in areas which have not been producing good seed crops. This cannot be explained from the data at hand, but reference can be made to very great differences in seed setting of red clover from year to year in which crop it has been admitted insect visitation is a necessity. Observations have indicated a great difference in the beneficial insect population in a given area from year to year. Apparently, favorable or unfavorable environmental conditions can cause a very rapid change in the insect population.

Despite emphasis placed on tripping, it should be remembered that many other factors affect alfalfa seed production. It is only too true that under some conditions all the flowers could be tripped and cross-pollinated and still set very little seed. Under other conditions, such as stimulation of the vegetative phase of growth as compared to the reproductive phase, or presence of harmful insects, such as *Lygus*, very few flowers may be produced. Apparently the balance which is necessary for reproductive development in alfalfa can very easily be tipped toward the vegetative phase and no doubt that is why alfalfa is such a high forage producer. There are many examples, however, in seed-producing areas where everything seems to be

favorable for a seed crop and yet the crop is very poor. Under these conditions a lack of tripping may be the determining factor.

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THE NITROGEN, ORGANIC CARBON, AND pH OF SOME SOUTHEASTERN COASTAL PLAIN SOILS AS INFLUENCED BY GREEN-MANURE CROPS[1]

RULON D. LEWIS AND JAMES H. HUNTER[2]

THE status of the nitrogen and carbon in the soil involving both actual content and ratio has been recognized as correlated with crop productivity. Both these constituents are normally low in the soils of the southeastern United States. According to the work of Jenny (3)[3], this is the result of the prevailing climatic conditons. This being true, it is important to know what level of nitrogen and carbon content is necessary in these soils to insure satisfactory crop production.

Albrecht (2) recognized the difficulties of raising the level of nitrogen and carbon in the soil under southern conditions and pointed out that it might even be impossible to build these up to the level of virgin soil. For many years southern leaders in agriculture have stressed the use of legumes as a means of maintaining crop production.

Many data are available indicating the value of legumes in maintaining yields, but there is a scarcity of data showing that nitrogen or carbon are increased to any appreciable extent over a period of years. It is the purpose of this paper to present data on the nitrogen and carbon content of three important Coastal Plain soils, under different green-manuring systems and management in order that some light may be shed on the economy of using legumes for the maintenance of crop production on these soils.

EXPERIMENTS ON GREENVILLE AND NORFOLK SANDY LOAMS

PLAN AND PROCEDURE

In these experiments varying amounts of vegetation from different crops were grown and returned to the soil for the purpose of making a study of their influence on the carbon and nitrogen relationships in the soil. The crop management systems used are ones which can be used in pecan and other orchards of the southeastern states. Details of the cropping systems and crops are given in Table 1. All the material grown under the various cropping systems was returned to the soil except in system H in which the ear corn and the seed cotton were removed. System A involved cultivation often enough during the summer to keep down the weeds and grass. All other systems involved sufficient cultivation to insure good crop growth. A 4–8–4 fertilizer[4] was applied at the rate of 400 pounds per acre annually to

[1]Contribution from the Division of Soil Fertility Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture, Albany, Georgia. Credit is due Dr. J. J. Skinner of the Bureau of Plant Industry, U. S. Dept. of Agriculture, in charge of soil fertility studies in the southeastern states, for guidance in developing these investigations. Received for publication April 27, 1940.

[2]Associate and Assistant Soil Technologist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 601.

[4]The fertilizer constituents are given in the order of nitrogen, phosphoric acid, and potash. The fertilizer was non-acid forming.

all systems except system E which received no fertilizer. Representative portions of the crops were harvested to get approximate yields of the above-ground growth just previous to turning in the crops, or at such time as seemed best to record the maximum production of green manure. Hereafter in this report the cropping systems will be referred to by the designated symbols, as A, B, C, etc., as given in Table 1.

Greenville and Norfolk sandy loam soils in the vicinity of Albany, Georgia, were used in this study.[5] Both soils are well drained. The A horizon of the Greenville soil is about 6 inches deep, is brownish red in color, while the B horizon is red and has undergone considerable illuviation. The A horizon of the Norfolk is about 8 inches deep and is light gray in color; the yellow B horizon does not contain as much colloidal material as the corresponding layer of the Greenville soil.

The mean annual rainfall for Albany, Georgia, is approximately 50 inches and the mean annual temperature about 69° F.

The Greenville soil was in peanuts the year preceding the experiment while the Norfolk soil grew native weeds and grass. No commercial fertilizer had been applied for a number of years.

Composite soil samples were taken from the A horizon of both soils at the beginning of the experiments and in December each year thereafter. The official A. O. A. C. method was used for nitrogen, the wet oxidation method of Adams (1) for carbon and the hydrogen electrode for the pH.

EXPERIMENTAL DATA

The yields are given as pounds of green weight per acre in Table 2 for the Greenville soil and in Table 3 for the Norfolk soil. The yields as an average for 4 years vary in the above-ground parts from 2,548 pounds per acre annually up to 41,034 pounds. There is a close similarity in the yields of the crops in the different systems on the two soils (4).

The data on the nitrogen and carbon contents for the Greenville soil are given in Table 4 and shown graphically in Fig. 1. It is evident that the nitrogen has been increased materially under all systems, and in most cases it has been doubled the original amount in the soil. The carbon has not increased so consistently. In all the systems except the two permanent cover crops, F and G, the carbon has dropped below the original level at least one year, but when the average for the period is compared with the original carbon content there are gains in all systems. Due to large increases in nitrogen as compared to the carbon the carbon-nitrogen ratio has been narrowed materially. In the cropping systems, the highest level of nitrogen occurred where the largest amounts of materials have been turned into the soil, systems B and D. Although there is some relationship between the amount of material returned to the soil and the accumulation of

[5]W. M. Van Cise and R. H. Waugh, pecan growers of the Albany, Georgia, section, contributed land and labor for these experiments. Their cooperation is appreciated. These experiments were inaugurated by E. D. Fowler, formerly of the Bureau of Plant Industry, now with the Soil Conservation Service, U. S. Dept. of Agriculture.

TABLE 1.—*Details of cropping systems used in the study of carbon and nitrogen relationships in Greenville and Norfolk sandy loam soils, Albany, Georgia.*

Type of cropping system*	1935		1936		1937		1938	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
A, Winter green manure	Austrian peas, vetch, and rye		Vetch and rye		Rye		Austrian peas, vetch, and rye	
B, Winter and summer green manure (largely legumes)	Austrian peas, vetch, and rye	Velvet beans	Vetch and rye	Cowpeas	Rye	Runner peanuts	Austrian peas, vetch, and rye	Velvet beans
C, Summer green manure		Velvet beans		Cowpeas		Runner peanuts		Velvet beans
D, Winter cereal and summer legume	Rye	Crotalaria	Oats	Crotalaria	Rye	Crotalaria	Rye	Crotalaria
E, Winter cereal and summer legume (not fertilized)	Rye	Crotalaria	Oats	Crotalaria	Rye	Crotalaria	Rye	Crotalaria
F, Kudzu permanent cover		Kudzu		Kudzu		Kudzu		Kudzu
G, Bermuda grass sod		Bermuda grass		Bermuda grass		Bermuda grass		Bermuda grass
H, Cash crop rotation with summer legumes		Corn and velvet beans		Cotton		Runner peanuts		Corn and velvet beans

*A 4-8-4 fertilizer was applied at the rate of 400 pounds per acre annually except as noted.

TABLE 2.—*Effect of different cropping systems on yield in pounds per acre of green-manure crops on Greenville sandy loam, Albany, Georgia.*

Type of cropping system*	1935		1936		1937		1938		Average annual green weight, lbs.
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	
A, Winter green manure	4,486	—	9,801	—	2,831	—	13,634	—	7,688
B, Winter and summer green manure (largely legumes)	6,316	16,770	13,504	7,971	12,415	25,482	15,028	20,038	29,381
C, Summer green manure	—	13,504	—	4,051	—	24,394	—	14,375	14,081
D, Winter cereal and summer legume	4,008	28,532	6,098	21,649	11,631	29,839	9,714	16,988	32,115
E, Winter cereal and summer legume (not fertilized)	2,091	12,850	2,396	8,799	1,089	10,934	1,307	7,318	11,696
F, Kudzu permanent cover	—	6,752	—	9,583	—	14,810	—	13,721	11,217
G, Bermuda grass sod	—	7,187	—	8,095	—	7,667	—	4,792	6,926
H, Cash crop rotation with summer legumes	—	16,770	—	—	—	20,691	—	5,009	14,157†

*A 4-8-4 fertilizer was applied at the rate of 400 pounds per acre annually except as noted.
†Three-year average; yield of cotton stalks in 1936 not taken.

TABLE 3.—*Effect of different cropping systems on yield in pounds per acre of green-manure crops on Norfolk sandy loam, Albany, Georgia.*

Type of cropping system*	1935		1936		1937		1938		Average annual green weight, lbs.
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	
A, Winter green manure	2,962	—	9,365	—	5,009	—	18,730	—	9,017
B, Winter and summer green manure (largely legumes)	3,398	13,504	12,632	7,710	11,543	23,305	17,424	15,246	26,190
C, Summer green manure	—	10,237	—	6,970	—	22,216	—	17,642	14,266
D Winter cereal and summer legume	3,333	25,483	8,843	39,552	13,504	36,373	17,250	20,909	41,034
E, Winter cereal and summer legume (not fertilized)	828	5,772	697	3,833	1,089	3,398	131	—	3,937
F, Kudzu permanent cover	—	5,336	—	8,538	—	12,415	—	14,810	10,275
G, Bermuda grass sod	—	871	—	4,225	—	—	—	—	2,548†
H, Cash crop rotation with summer legumes	—	10,563	—	—	—	20,691	—	6,839	12,698‡

*A 4–8–4 fertilizer was applied at the rate of 400 pounds per acre annually except as noted.
†Two-year average. The growth on this plat was largely native grasses and broom sedge after 1936. These were cut at intervals during the year and allowed to emain on the soil but no record of yield was taken.
‡Three-year average; yield of cotton stalks not taken in 1936.

TABLE 4.—*Content of organic carbon and total nitrogen, also carbon-nitrogen ratio on Greenville sandy loam soil at different times after various treatments.**

Type of cropping system†	1935			1936			1937			1938			Averages		
	C, %	N, %	C/N	C, %	N, %	C/N	C, %	N, %	C/N	C, %	N, %	C/N	C, %	N, %	C/N
A, Winter green manure	0.302	0.0376	8.0	0.312	0.0447	6.9	0.405	0.0711	5.6	0.302	0.0569	5.3	0.330	0.0526	6.3
B, Winter and summer green manure (largely legumes)	0.460	0.0564	8.1	0.216	0.0666	3.2	0.356	0.0788	4.5	0.465	0.0818	4.9	0.374	0.0709	5.3
C, Summer green manure	0.356	0.0438	8.1	0.272	0.0512	5.3	0.429	0.0599	7.1	0.428	0.0617	5.2	0.371	0.0542	6.8
D, Winter cereal and summer legume	0.412	0.0578	7.1	0.288	0.0697	4.1	0.496	0.0818	6.0	0.429	0.0682	6.2	0.406	0.0694	5.9
E, Winter cereal and summer legume (not fertilized)	0.316	0.0466	6.7	0.277	0.0577	4.8	0.436	0.0726	6.0	0.308	0.0553	5.5	0.334	0.0581	5.7
F, Kudzu permanent cover	0.367	0.0508	7.2	0.311	0.0639	4.8	0.436	0.0694	6.2	0.459	0.0826	5.5	0.393	0.0667	5.9
G, Bermuda grass sod	0.403	0.0515	7.8	0.333	0.0620	5.3	0.503	0.0816	6.1	0.380	0.0746	5.0	0.405	0.0674	6.0
H, Cash crop rotation with summer legumes	0.326	0.0459	7.1	0.260	0.0585	4.4	0.441	0.0706	5.9	0.327	0.0585	5.5	0.339	0.0584	5.8

*The original average organic carbon and total nitrogen of soil samples taken in the fall of 1934 of all the plats were 0.306% carbon and 0.0319% nitrogen, a C/N ratio of 9.6. There were only slight variations in the plats.

†A 4-8-4 fertilizer was applied at the rate of 400 pounds per acre annually except as noted.

nitrogen and carbon, this is definitely not in proportion to the amount of green manure added.

The data for the nitrogen and carbon in the Norfolk soil are given in Table 5 and shown graphically in Fig. 2. Both nitrogen and carbon have been increased rather consistently by all the cropping systems, with a tendency for a gradual build up of the nitrogen during the first three years and then a decline for the fourth year. The carbon shows much more variation, but the general trend is for the carbon to accumulate more rapidly than the nitrogen. Thus the carbon-nitrogen ratio has been broadened in most cases. In the average for the period,

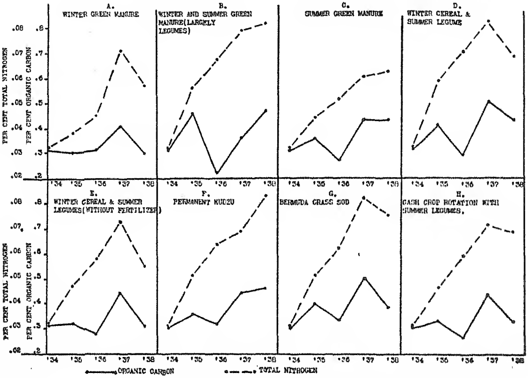

FIG. 1.—Annual change in total nitrogen and organic carbon in Greenville sandy loam soil under different systems of management. All plots except E received 400 pounds annually of 4–8–4 fertilizer.

there are only three systems that have narrowed the carbon-nitrogen ratio below the original. These are the two systems with winter cereal and summer legume (D and E) and the kudzu (F). The greatest conservation of both carbon and nitrogen has been from the bermuda grass sod. System D, which received the greatest amount of green manure during the four years, ranks fifth in average carbon and fourth in average nitrogen. There seems to be no relationship between the amount of green manure added and the nitrogen and carbon accumulated during the period under study.

For the purpose of showing the contrast in the two soils, the relative yields of green material per acre and the average nitrogen and carbon contents of the two soils have been brought together in Fig. 3. First it will be noted that there is a marked similarity between the yields of the crops on the two soils. This is in contrast to the high nitrogen level occurring with all systems on the Greenville soil com-

TABLE 5.—*Content of organic carbon and total nitrogen, also carbon-nitrogen ratio on Norfolk sandy loam soil at different times after various treatments.**

Type of cropping system†	1935			1936			1937			1938			Average		
	C, %	N, %	C/N	C, %	N, %	C/N	C, %	N, %	C/N	C, %	N, %	C/N	C, %	N, %	C/N
A, Winter green manure..............	0.426	0.0306	13.9	0.386	0.0388	9.9	0.593	0.0584	10.1	0.380	0.0345	11.0	0.446	0.0406	11.0
B, Winter and summer green manure (largely legumes).....	0.440	0.0299	14.7	0.442	0.0385	10.9	0.555	0.0613	9.0	0.544	0.0465	11.6	0.495	0.0441	11.2
C, Summer green manure..............	0.512	0.0441	12.4	0.469	0.0477	9.8	0.543	0.0606	8.9	0.476	0.0473	10.0	0.500	0.0499	10.0
D, Winter cereal and summer legume......	0.434	0.0341	12.7	0.451	0.0408	11.0	0.446	0.0683	6.5	0.464	0.0529	8.7	0.449	0.0490	9.2
E, Winter cereal and summer legume (not fertilized).......	0.213	0.0355	6.0	0.463	0.0435	10.6	0.595	0.0560	10.6	0.386	0.0369	10.44	0.414	0.0430	9.6
F, Kudzu permanent cover................	0.252	0.0383	6.5	0.552	0.0550	10.0	0.597	0.0623	9.5	0.554	0.0569	9.5	0.489	0.0531	9.2
G, Bermuda grass sod..	0.568	0.0445	12.7	0.487	0.0547	8.9	0.778	0.0780	9.9	0.531	0.0513	10.3	0.591	0.0571	10.4
H, Cash crop rotation with summer legumes.	0.493	0.0327	15.0	0.321	0.0400	8.0	0.485	0.0573	8.4	0.440	0.0441	9.9	0.435	0.0435	10.0

*The original average organic carbon and total nitrogen content of soil samples taken in the early fall of 1934 of all the plats were 0.293% carbon and 0.0299% nitrogen. Carbon-nitrogen ratio of 9.8. There were only slight variations in the plats.

†A 4-8-4 fertilizer was applied at the rate of 400 pounds per acre annually except as noted.

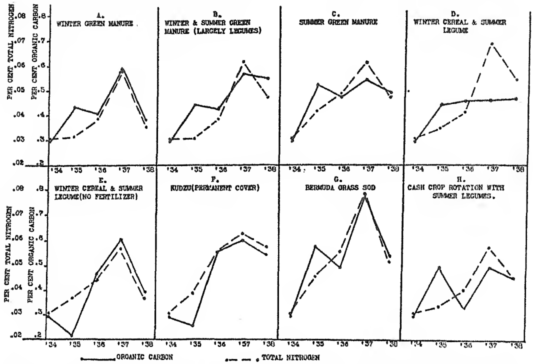

FIG. 2.—Annual change in total nitrogen and organic carbon in Norfolk sandy loam soil under different systems of management. All plots except E received 400 pounds annually of 4–8–4 fertilizer.

pared to the nitrogen level in the Norfolk soil. A further contrast is shown by the higher level of carbon for all the systems on the Norfolk

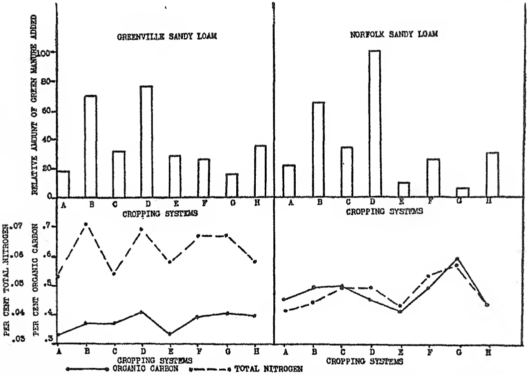

FIG. 3.—The relative amount of green manure added to the soil and the average total nitrogen and organic carbon in Greenville and Norfolk sandy loam soils under different systems of management, 1935–38, taking treatment D on Norfolk sandy loam as 100.

compared to the Greenville soil. Thus there is a marked difference in the carbon-nitrogen ratio from the same systems of management on the two soils. There has been a narrowing of the carbon-nitrogen ratio in the Greenville soil largely due to the accumulation of nitrogen, whereas there has been a slight broadening of the carbon-nitrogen ratio in the Norfolk soil due to a greater accumulation of carbon. It is apparent that conditions are more favorable in the Greenville than in the Norfolk soil for the complete destruction of carbonaceous materials. Likewise, there is a greater conservation of nitrogen in the Greenville soil. It is believed that both of these are due to greater leaching of available nitrogen in the Norfolk soil since it has considerably less colloidal material, silt and clay, especially in the B layer. The yield of the crops from system D on the two soils tends to support this view. In this system, the soil is occupied the maximum amount of time during the year, thus leaching should be held to a minimum. The yields of the crops and especially the rye in the winter are greater for the Norfolk than for the Greenville soil. (See Tables 2 and 3.)

The pH data for the soils are given in Table 6. The original pH of all the plats on both soils ranged around 5.8 with only slight variations in plats. It will be noted that the pH has gradually become lower under all systems of management on both soil types with only one exception. This is on the Greenville soil under system F (kudzu) where the pH is about the same after four years of treatment as at the beginning.

EXPERIMENT ON TIFTON SANDY LOAM

PLAN AND PROCEDURE

In 1926, a series of corn and cotton green manure plats were established on Tifton sandy loam soil located at the Georgia Coastal Plain Experiment Station at Tifton, Georgia.[6] These plats have been carried on continuously since that time. Details of the experiment are described elsewhere (6). Two series of plats are planted to the same winter green-manure crops each year, while the summer crops of corn and cotton are rotated. The green-manure crops include Austrian winter peas, monantha vetch, hairy vetch, and Abruzzi rye. For the cotton and corn that follow the green-manure crops, the plats are divided so that one-half of each plat receives nitrogen in the fertilizer and the other half receives none. A 3–9–5 and 0–9–5 fertilizer at the rate of 1,000 pounds per acre are applied to the cotton and a 2–10–4 and 0–10–4 at the rate of 500 pounds per acre are applied to the corn.[7] In presenting the data given here, only the averages for the different green-manure crops with and without nitrogen in the fertilizer are given.

[6]This experiment is cooperative between the Divisions of Soil Fertility Investigations and Forage Crops and Diseases of the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Georgia Coastal Plain Experiment Station. The field phases of the work are under the supervision of J. L. Stephens of the Bureau of Plant Industry at Tifton, Georgia.

[7]The fertilizer constituents are given in the order of ammonia, phosphoric acid, and potash. The 2 and 3% ammonia are equivalent to 1.65 and 2.47% nitrogen, respectively.

TABLE 6.—*The pH values of Greenville and Norfolk sandy loam soils following various cropping systems.*

Type of cropping system*	Greenville sandy loam†					Norfolk sandy loam†				
	1935	1936	1937	1938	Av.	1935	1936	1937	1938	Av.
A, Winter green manure	6.02	5.57	5.64	5.12	5.59	5.72	5.75	5.79	5.20	5.62
B, Winter and summer green manure (largely legumes)	6.03	5.78	5.52	5.10	5.61	5.57	5.48	5.54	5.06	5.41
C, Summer green manure	5.85	5.77	5.45	5.27	5.59	5.65	5.32	5.62	5.15	5.44
D, Winter cereal and summer legume	5.89	5.73	5.63	5.46	5.68	5.66	5.66	5.67	5.37	5.59
E, Winter cereal and summer legume (not fertilized)	6.13	5.78	5.76	5.69	5.84	5.87	5.63	5.76	5.48	5.69
F, Kudzu permanent cover	5.60	5.60	5.50	5.83	5.63	5.64	5.33	5.50	5.25	5.43
G, Bermuda grass sod	5.73	5.70	5.52	5.46	5.60	5.83	5.81	5.55	5.42	5.65
H, Cash crop rotation with summer legumes	5.77	5.55	5.64	5.27	5.56	5.97	5.93	5.55	5.27	5.68

*A 4-8-4 fertilizer was applied at the rate of 400 pounds per acre annually except as noted.
†The original pH of Norfolk and Greenville soils at beginning in the fall of 1934 was pH 5.8.

The soil in this experiment is a Tifton sandy loam. It resembles the Norfolk except that the subsoil has a darker yellow color with more fine silt and clay and it contains rounded iron oxide and sand-clay pebbles which make up about 30% of the volume of the A and B horizons. The soil samples were collected to a depth of 8 inches which is the thickness of the A horizon.

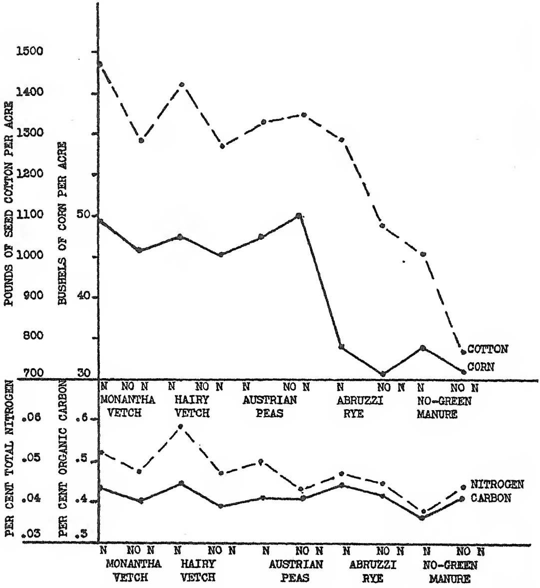

FIG. 4.—Twelve-year average yield of cotton and corn in rotation following different green-manure crops with and without additional nitrogen. The total nitrogen and organic carbon at the end of the period. Tifton sandy loam.

EXPERIMENTAL DATA

The chemical analysis of the soil sampled in 1939 and the average annual crop yields are shown in Table 7 and graphically in Fig. 4. The chemical data represent the status of the total nitrogen, organic carbon, and pH of this soil after 12 years of continuous cropping with the use of the different green-manure crops as compared to no green manuring.

TABLE 7.—*Influence of winter green-manure crops on carbon and nitrogen content of Tifton sandy loam soil and on yield of cotton and corn, experiment started in 1926.*

Green manure crop		pH 1939†	Nitrogen, 1939, %†	Organic carbon, 1939, %†	C/N ratio	Av. yield of green manure in lbs. per acre, 1926–37‡	Av. yield of corn in bu. per acre, 1926–37‡	Av. yield of seed cotton in lbs. per acre, 1926–37‡
Monantha vetch:	A*	5.4	0.052	0.428	8.2	—	48.6	1,474
	B	5.3	0.047	0.401	8.5	19,877	45.8	1,286
Hairy vetch:	A	5.2	0.058	0.444	7.6	—	47.8	1,424
	B	5.3	0.047	0.393	8.4	12,772	45.7	1,266
Austrian peas:	A	5.35	0.050	0.409	8.2	—	47.6	1,333
	B	5.3	0.043	0.406	9.4	12,837	50.3	1,351
Abruzzi rye:	A	5.7	0.047	0.442	9.4	—	34.4	1,290
	B	5.75	0.045	0.421	9.3	6,510	30.6	1,079
No green manure:	A	5.8	0.037	0.364	9.8	—	33.9	1,010
	B	5.5	0.044	0.407	9.2	—	31.2	772

*A, nitrogen in fertilizer; B, no nitrogen in fertilizer.

†The pH of the soil of the various plats at the beginning of the experiment in 1926 ranged very near 6.1, with insignificant variations from plat to plat. The nitrogen of the plats was 0.041% for eight plats, 0.040% for one and 0.042% for one, averaging 0.041%. The carbon content of the two plats averaged 0.43% with variations from 0.39 to 0.44%.

‡The yields of green manure crops, corn, and cotton were taken from the 18th Annual Report of the Georgia Coastal Plain Experiment Station, Bulletin 29, pages 36 and 37 (1937–38).

It will be noted that very good average yields of corn and cotton have been produced where all three of the legume green-manure crops were grown and that the rye has produced yields of cotton that are higher than with no green manure, but not as high as with the legumes. In the case of corn after the rye, the yields are about the same as with no green manure. The maximum yield of cotton was produced following monantha vetch where nitrogen was added in the fertilizer whereas the maximum yield of corn was produced following Austrian peas where no nitrogen was added in the fertilizer. The hairy vetch gave the second highest yield of cotton where nitrogen was added in the fertilizer and the monantha vetch the second highest yield of corn also with nitrogen added in the fertilizer. The Austrian peas without any nitrogen added in the fertilizer gave higher yields of both cotton and corn than did either monantha or hairy vetch under the same condition. In this experiment where no nitrogen was added in the fertilizer, Austrian peas seem to be the most efficient green-manure crop.

The total nitrogen and the organic carbon in the soil appear to be rather closely correlated with the yields of the crops in the case of the data for the monantha and hairy vetch. This correlation is not maintained when the Austrian peas and the rye data are considered. In general, however, the largest crop yields are from the same plats showing the highest nitrogen and carbon. Here again, as with the yields, the Austrian peas without nitrogen added in the fertilizer are an exception. Neither the nitrogen nor the carbon in the soil on this plat are as high as from the rye plats, yet the yields of the crops are considerably above those from the rye plats. Therefore, factors other than the total nitrogen and the organic carbon must have played a part in the yields of the crops produced. While one of the factors involved may be the availability of the nitrogen during the growth of the succeeding crops, the data would indicate that a factor other than nitrogen is involved.

The pH of this soil is lower on all plats than at the beginning of the experiment, being a little more pronounced on the plats receiving leguminous green manure.

DISCUSSION

The data presented tend to lead to the conclusion that it is not of great importance that the nitrogen and carbon be built up to high levels in order to produce good crops on the soils studied. For example, good yields of cotton and corn have been produced on the Tifton soil with an organic carbon content of about 0.4% and a nitrogen content of about 0.050%; on the Norfolk soil with an organic carbon content of 0.44% and a nitrogen content of 0.044%; and on the Greenville soil with an organic carbon content of 0.34% and a nitrogen content of 0.058% (4). Such levels as these were maintained with the use of green-manure crops in rotations with cash crops. Higher levels of these constituents were attained with the use of more intense systems of green manuring, but the higher levels were not in proportion to the much larger amounts of green manure added, thus indicating that heavy losses of these constituents probably occur when an effort is

made to build them up to a very high level. This is doubtless what Pieters and McKee (5) had in mind when they pointed out that the object of green manuring must be to maintain rather than build up organic matter in the soil. The economical system of green manuring would seem to be one in which annual green-manure crops are grown and returned to the soil at such a time as to supply the succeeding crops with the maximum amount of the decomposition products of the green manure.

Albrecht (2), in discussing the maintenance of organic matter, pointed out that the value of organic matter lies in its dynamic nature and that it functions only as it is destroyed. The data secured under systems D and E in this study seem to substantiate this view. In these two systems the same crops (rye in winter and crotalaria in summer) are grown, system D with commercial fertilizer and system E without fertilizer. The producing power of the soils under these two systems has been greatly modified as is shown in Tables 2 and 3. The nitrogen and carbon data under these two systems do not show such marked differences as to explain the difference in the crop growth on these plats. It is true that the carbon and nitrogen are maintained at slightly higher levels under system D with fertilizer, but the relationship of the carbon to the nitrogen is essentially the same for both of the systems; the average carbon-nitrogen ratios for systems D and E are 5.9 and 5.7 for the Greenville and 9.2 and 9.6 for the Norfolk soils, respectively. Therefore, the difference in the carbon and nitrogen relationships for the two systems does not seem adequate to explain the difference in the producing power of the two soils and neither do the slightly higher levels of the two constituents. It should be noted that values for the carbon-nitrogen ratios in each of the soils in these experiments are distinctly lower than values ordinarily found for surface soils of humid regions. Thus it would seem that the influence of the commercial fertilizer on the dynamic nature of the organic matter under these two systems must play an important part in the producing power of these soils. This presents a problem that needs further study.

SUMMARY

The total nitrogen, organic carbon, and pH of Greenville, Norfolk, and Tifton sandy loam soils under various systems of green-manuring are reported. These systems include the growing of summer and winter green-manure crops in different cropping systems and with varying crop management for soil improvement. The soils used in the experiments are typical of the soils of the same types in the southeastern coastal plain.

The total nitrogen is increased and the organic carbon either increased or maintained under all systems in the experiments. In no case were these constituents raised to levels that correspond to the levels reported for fertile soils in latitudes farther north.

In the Greenville soils nitrogen was conserved at the expense of organic carbon with a resulting narrow carbon-nitrogen ratio of about 6.0, under all systems of management. In the Norfolk soil more accumulation of carbon than of nitrogen was obtained under most of the

systems with the result that the carbon-nitrogen ratio was broadened to around 10.0. The Tifton soil is intermediate in this respect showing a carbon-nitrogen ratio of about 8.0.

The pH is generally lowered by the use of green manures on all the soils.

Satisfactory yields of cotton and corn were produced with the following approximate levels of organic carbon and total nitrogen where green manures and commercial fertilizer were applied: 0.44% carbon and .044% nitrogen for the Norfolk soil; 0.34% carbon and 0.058% nitrogen for the Greenville soil; and 0.40% carbon and 0.050% nitrogen for the Tifton soil.

More than one green-manure crop in succession results in higher nitrogen and carbon than one crop per year, but the added gain is not sufficient to justify the loss incurred by tying up the land for the time required. The most economical system for using green manure seems to be one in which the most important cash crop follows the green-manure crop.

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MANAGEMENT—A CURE FOR OVERGRAZED RANGE[1]

AVERIL B. NIELSON[2]

EARLY settlers who came to the Pacific Coast bunchgrass regions saw the finest grassland west of the Rocky Mountains. This grass, covering approximately 61,000,000 acres of land in western Montana, southeastern Idaho, eastern Washington, and central Oregon (8),[3] provided forage for immense herds of deer, elk, buffalo, and antelope, and was to become a valuable range for domestic livestock. During the first years of settlement, abundance of forage and a succession of mild winters provided excellent conditions for new ranchers, and it was not deemed necessary to provide hay or other supplemental feed (7).

Prior to 1861, stockmen suffered heavy losses. Indian wars of the late fifties were a contributing factor. Immediately following the Indian wars, when the stock industry was being re-established, the big snow and freeze of 1861–62 is reported to have killed 90% of the domestic stock in the Washington Territory. Undaunted by these reverses, stockmen brought new herds from Oregon, California, and the East, and did a lucrative business until 1880 when another severe winter is said to have taken a toll of 50 per cent of all livestock. This loss, coupled with still another severe winter just 10 years later, broke up most of the large outfits (7).

EARLY METHODS OF MANAGEMENT

Although the available range was being diminished both in area and in quality, the number of cattle and sheep increased, not only in the Northwest but over most of the western range. Supply overstepped demand with the usual result—prices slipped, then dived downward. Choice beef on the Chicago market in 1885 brought $2.50 a hundred weight. Because it was not profitable to ship $2.50 beef, stockmen held their cattle on the range. Herd increases were such that the range could not support these large numbers under continuous use. The era of overuse was in full swing, and from then to the present most of the range has been given no chance to recover from this early "beating" (5).

As the better ranges were broken for cultivation, the poorer areas were more and more heavily used, and it was not long before many of the ranges were seriously injured. As a result, forage production has been reduced by more than 50% and, on many areas, to only a fraction of the virgin forage yield.

PRESENT CONDITION OF RANGE

As a result of lowered vitality of the more desirable forage plant, not only has production been reduced, but the weakened plants

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[1]Contribution from the Soil Conservation Service, U. S. Dept. of Agriculture. Received for publication May 4, 1940.

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[3]Figures in parenthesis refer to "Literature Cited", p. 606.

have become unable to produce fertile, vigorous seed. Meanwhile, the plants of low palatability produce abundant viable seed, setting up bold competition to the weakened desirable plants (6).

Observations of grazing during the three years, 1936, 1937, and 1938, on bunchgrass ranges of southeastern Washington show that growth on moderately-used pastures starts 10 days or two weeks earlier than on pastures overgrazed the previous spring (2).

Often insufficient vegetal cover is remaining to prevent accelerated erosion on many heavily-grazed areas, even when the number of plants present is satisfactory as far as density is concerned (3).

It is difficult to appreciate the great change in the condition of range lands in this region during the past 60 years, where excessive use has been the rule. About 19,000,000 acres of this once virgin grassland in eastern Washington and northeastern and northcentral Oregon have been broken and planted to wheat. Of the remaining 42,000,000 acres, 3,000,000 acres are now classed as severely eroded, with the mantle of top soil lots or worn so thin that the desirable forage plants which it once supported no longer thrive. This vast area will probably remain in its cover of the unpalatable grasses and weeds that now occupy these soils.

An additional 7,000,000 acres suffering from serious erosion not only is subjected to the pernicious invasion of the low value plants now permanently established on the severely eroded soils, but has lost so much top soil that it is doubtful whether, even under the best possible management, these grazing areas can be restored to as much as half their original grazing capacity.

The remainder of the grass range, about 32,000,000 acres, displays lesser degrees of erosion and plant depletion. Fortunately, this greater area can be restored to approximately four-fifths of its original grazing capacity by immediate and continuous application of conservation practices (5).

Run-off and erosion studies carried on by the Intermountain Forest and Range Experiment Station show comparisons of soil and water losses on granitic soils from four different types of ranges in southern Idaho (4). Range lands in southeastern Washington and northeastern Oregon that have similar soil and vegetation as those studied in southern Idaho can be expected to yield similar results under the same treatment. The data obtained by the Intermountain Forest and Range Experiment Station in southern Idaho show that on wheatgrass range virtually no run-off or erosion occurred, as compared with an average of 45.4% run-off and 3.69 tons per acre of eroded material on the downy-chess range, the lupine-needlegrass range, and annual-weed range.

The wheatgrass cover was surprisingly effective in retarding run-off and preventing erosion under all conditions, even on 40% slopes, and with high rainfall intensities, under practices that stimulated grazing. Although much less effective than wheatgrass, downy-chess, from which there was an average of 25.5% run-off and 1.05 tons of eroded soil per acre, was about twice as effective for controlling run-off as lupine-needlegrass and annual weed cover types, and from two to seven times more efficient in preventing erosion.

Steepness of slope in these studies was the most important variable influencing run-off and erosion on the three types of range (1).

STUDIES OF CARRYING CAPACITY

The original vegetal condition of the range, as determined from studies of inaccessible areas and old cemeteries, shows a dense cover of thrifty bluebunch wheatgrass (*Agropyron spicatum*), Idaho fescue (*Festuca idahoensis*), and perennial broad-leaved forbs, including lupine, balsamroot, yarrow, and other perennial species that compose the major portion of the climax cover. This type of vegetation not only provides a good surface cover (up to 34% density), but also fills the topsoil with an excellent network of roots, holding the soil in place, and aiding in the penetration and infiltration of moisture. Such range has been found to carry 96 animal unit months per 100 surface acres (2).

The present condition of vegetation of virtually all this range shows a decrease in plant vigor and forage density resulting from close grazing year after year. Ranges that have been grazed moderately in the past have an average density up to 25% and a carrying capacity of 70 animal unit months per 100 acres. The severely grazed range has a density of only 12% and a carrying capacity of 11 animal unit months per 100 acres (2).

RANGE PLOT STUDIES

Too early and too heavy grazing is generally believed to affect the composition and density of vegetation to a degree depending upon intensity of use, type of vegetation, character of the soils, degree of slope, and climatic conditions. Much has been published to show the stockmen and farmer the evil effects of overuse, but little has been done in southeastern Washington based on permanent study plots to determine the practicability of different methods of management, or what results can be expected from proper range management.

Range plots were set up in 1936 and 1937 in southeastern Washington to study further the effects of overuse of native grass lands and the value of protection in correcting the effects of overuse. These plots were located on south exposures having relatively shallow soil and where the ranges had been severely grazed in the past and, as a result, were in a more depleted condition than on other exposures.

The 20-year average annual precipitation of the area under study was 19.62 inches; for 1936 it was 13.89 inches; for 1937, 16.37 inches. The soils of the area, prairie silt loam, are highly erodible, whether they are overgrazed native grasslands or seeded pasture, and they tend to wash and gully rapidly following depletion of the organic matter. Accelerated erosion of exposed and trampled soil is a serious problem of both range lands and seeded pasture.

Permanent meter-square quadrats were established on representative ranges that were to be managed properly under a deferred and rotation system of grazing. The quadrats were charted during July 1936, and were recharted again in 1938. The average forage density in 1936 was 3.47% basal density. The plant vigor was very low. The

average height of the bluebunch wheatgrass was 6 inches and that of the Idaho fescue 3 inches.

In 1938, the average forage basal density for all species was 5.03%. The bunchgrasses showed definite improvement in plant vigor and basal density. The height of the bluebunch wheatgrass was 25 inches, an increase of 19 inches over 1936. The height of the Idaho fescue was 10 inches, or an increase of 7 inches. The pasture increased 43% in forage density in the two years and approximately 112% in carrying capacity, as compared with the 1936 condition.

Another severely depleted range was selected to carry on a study of the effect of two years' protection of severely overgrazed range. The native bunchgrasses had almost disappeared; only a few small weakened plants remained as evidence of the original vegetative cover. Barbed-wire fences were constructed on quarter-acre areas representative of the surrounding range. Permanent meter-square quadrats were established, and the vegetation was charted within the exclosures and at nearby points outside, to serve later as comparisons in the study of the vegetal recovery of the bunchgrasses.

The basal ground cover and height of the bluebunch wheatgrass on the outside of the enclosures at the time these plots were recharted on May 5, 1938, was about the same as when first charted in 1936. The basal density of the bluebunch wheatgrass on the unprotected plot was 0.57%, the forage height was 7 inches, and the forage yield 10.9 grams per square meter, or 97.15 pounds per acre green weight clipped 1½ inches above the ground level. The basal density on the protected plot was 1.90%, the forage height had increased to 18 inches, and the forage yield was 207.0 grams per square meter, or 1,841.81 pounds per acre green weight, an increase of 19 times in two years.

The range on which a one-year protection plot was established in the spring of 1937 was in better condition than the one on which the two-year study was made. This is shown in the basal densities of the bluebunch wheatgrass. The physiographic, climatic, and soil conditions were much the same as described for the two-year study. Permanent meter-square quadrats were established within and near the enclosures. These quadrats serve as records for later comparisons on the plant recovery.

In 1938, on the grazed area, basal density for the bluebunch wheatgrass was 0.49%, the forage height was 8 inches, and the forage yield was 79.3 grams per square meter, or 704.35 pounds per acre green weight. The basal density of the protected plot was 2.72%, forage height 16 inches, and yield 275.5 grams per square meter, or 2,428.8 pounds per acre green weight, an increase of 3.44 times the forage yield of the grazed range.

DISCUSSION AND SUMMARY

Range studies were made to determine the relative rate of recovery of key species, namely, bluebunch wheatgrass (*Agropyron spicatum*) and Idaho fescue (*Festuca idahoensis*), under proper management and protection as a basis for recommendations and adjustments in range management plans. Plots were located in pastures which were

owned by local ranchers. Neighboring farmers and stockmen have had an opportunity for regular observation.

The following conclusions were reached as a result of the plot studies:

1. Bluebunch wheatgrass starts growth 10 days to two weeks earlier on pastures moderately used than on those overgrazed the previous spring.

2. Improper management not only reduces the yield of the better forage but also exposes the soil to serious erosion.

3. Studies of the virgin bunchgrass range revealed an estimated carrying capacity per 100 surface acres of 96 animal unit months. Estimated carrying capacity was 70 animal unit months on moderately over-grazed range and only 11 animal unit months per 100 surface acres on severely overgrazed range.

4. Range properly managed under a deferred and rotation system of grazing increased 43% in forage density and 112% in carrying capacity in two years.

5. Bluebunch wheatgrass severely overgrazed previous to protection increased approximately 19 times in forage yield under two years protection from grazing.

6. One-year's protection brought an increase of 3.44 times in forage yield of the bunchgrass the following season.

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SUNFLOWER AS AN INDICATOR PLANT OF BORON DEFICIENCY IN SOILS[1]

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During the season of 1935 walnuts containing poorly developed kernels were produced in both irrigated and non-irrigated orchards on certain soil types. Soil moisture determinations made during the growing season in these orchards showed that the moisture was always above the wilting percentage. On the other soil types walnuts containing heavy, well-developed kernels were produced although the soil moisture attained the wilting percentage by harvest. Up to the present, therefore, it has not been possible to relate poor filling entirely to unsuitable moisture conditions.

Soil moisture studies have been made in walnut and filbert orchards of the Willamette Valley since 1930. The wilting coefficients have been determined by the use of plants to extract the moisture in the soils to the wilting point (5).[3] Buckwheat, oats, wheat, coleus, and several types of sunflowers were used in tests to ascertain their suitability as indicator plants in making the wilting point determinations. With the more fertile soils all of the plants made satisfactory growth, but with some of the heavier and poorer soils and especially those taken from the deeper horizons, most plants failed to make satisfactory growth. Of the plants tested, the common sunflower proved the most satisfactory in some cases but not in others. Attempts to grow sunflowers on some soils by planting seed in soil taken from a depth of 4 to 6 feet resulted in complete failure. In the case of soil taken from a depth of 6 feet or more, only the cotyledonary or seed leaves developed and the terminal bud died. The plants grown in the soil taken from a depth of 4 feet made a fair growth for a short time, but later the newer leaves became chlorotic and distorted.

Unsuccessful attempts were made to provide conditions satisfactory for normal growth of the sunflower indicator plants by supplying them with a so-called basal nutrient solution.[4] When such a nutrient solution was used regularly the cotyledons of the sunflower plants growing in soil taken at a depth of 6 feet or deeper sometimes ex-

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[3]Figures in parenthesis refer to "Literature Cited", p. 621.

[4]The "basal nutrient solution" supplied calcium, magnesium, potassium, sulfur, phosphorus, and nitrogen. This type of nutrient mixture was at one time called a complete nutrient before the importance of minor elements was recognized.

panded to several times the normal size and thickness, but the terminal buds would not grow. In soil taken from the fourth foot or nearer the surface of the same profile the plants made a larger growth, developing one or more pairs of true normal leaves. The symptoms of malnutrition of the plants were slower in appearing when watered with a nutrient solution, but they ultimately developed and to the same degree. Furthermore, large sunflower plants with strong root systems when transplanted from flats to the soil cans used for wilting percentage determinations and watered with a basal nutrient solution for 10 days to establish a root system developed the abnormal conditions of the leaves and buds before the tests were completed.

Studies were undertaken in 1936 to determine if some element was deficient in the soils of the walnut orchards which produced poorly filled nuts. In addition to the usual elements contained in a full nutrient solution, zinc, manganese, copper, boron, and others were included singly in the solutions used. The only normal plants grown on the soil taken from the 4 to 6 feet horizons were those that received boron. The abnormalities of the sunflower plants grown on soils without boron were identical to those observed during the wilting point studies. This led to more extensive studies with other soil types to determine the extent of the boron deficiency and its possible relation to the filling of walnut kernels.

METHODS

SOIL TYPES STUDIED

In this study, soils of the following series were used: Sites and Melbourne of sandstone and shale origin; Aiken and Olympic of igneous rock origin; Salkum, Carlton, Amity, and Willamette of the old valley filling; and Newberg of the recent river bottom soils. For the sake of brevity and simplification, only the results obtained with the Aiken, Amity, Melbourne, and an unidentified soil from the Dalles, Oregon, are herein reported. The results obtained with the other soils are similar. Soil samples were taken in the orchards and in the same locations where moisture studies had been maintained for several years. The first foot of soil was divided into two samples, 0–6 and 6–12 inches; the deeper samples were taken at intervals of 1 foot to a depth of 10 feet. These samples were taken to the greenhouse where they were sifted and placed in the cans in which the plants were grown.

TECHNIC

All plants were grown on the various soil samples in No. 1 tall cans of charcoal plate about 3×6 inches in size with the inner surface coated with lacquer. The lacquered cans were used to avoid the plate being pitted by the soil solutions. Samples of 400 grams of soil were placed in each can since tests with this small amount of soil quickly showed which elements most limited the growth of plants.

There were four replications in each series. Two of the treatments received no boron and two received boron in addition to whatever other nutrient was used. In preliminary studies, solutions containing boron were made up from borax so that 1, 2½, 25, and 125 parts of boron could be added conveniently to one million parts of soil by weight. When boric acid was used in place of borax the results were similar. The effects of the elements N, P, K, and S were studied singly and in combinations. Then each element in turn was omitted from the "basal nutrient

solution". Nitrogen was supplied as calcium nitrate; phosphorus and potassium as a mixture of KH_2PO_4 and K_2HPO_4 when both potassium and phosphorus were needed. Potassium chloride was used to supply potassium without the phosphorus, and $CaH_4(PO_4)_2$ to supply phosphorus without the potassium. Sulfur was supplied as magnesium sulfate or as calcium sulfate. To determine the effects of these various solutions on plant growth when added to soil samples taken from a complete soil profile required a total of 456 cans.

Seven sunflower seeds were planted in each can and later each culture was thinned to five plants. The plants were started sometimes by watering the soil with distilled water and sometimes by watering with nutrient solutions from the first. All nutrient treatments were applied in the form of dilute solutions of a strength similar to that commonly used in water culture work. Not more than 1,000 cc of culture solution were added to a single can during the period of study. This provided enough of the essential elements N, P, K, and S for at least 15 grams dry weight of growth or more than the maximum growth yet obtained per can. The actual concentrations of solutions used were such as to provide 0.0351 gram K, 0.02 gram N, 0.0217 gram P, 0.0217 gram Ca, and 0.0168 gram Mg in 100 cc of solution. The application in any one day usually did not exceed 50 cc of nutrient solution. Toward the end of the period of study the plants were usually watered with distilled water to avoid overfeeding with nutrients. In the early growth stages, additional water needed for growth other than that supplied by the nutrient solution was provided as distilled water and watering was done once or twice daily as needed. Need for water was determined at first by daily weighing of the cans to determine the loss of moisture. Later, appearance of the soil and past experiences were the guide to watering. The usual procedure was to add nutrient solution on alternate days, keeping a record of the amount added.

Notes were made weekly, as a rule. When the first symptoms of nutritional disturbances appeared, they were recorded and described, and again at the end of the growth period a more detailed record was made to identify and describe the appearance of plants receiving different treatments. Appearance of the foliage and type of growth resulting from the omission of various elements were described when the omissions resulted in striking symptoms. In most cases measurements of the height of the plants were made at weekly or 10-day intervals and each measurement reported is the average of 10 plants. At the end of the experiment the top growth was harvested, dried, and weighed.

RESULTS OF STUDY

BORON DEFICIENCY SYMPTOMS IN THE SUNFLOWER

With extreme boron deficiency, the growth of the sunflower plant was restricted to the cotyledonary or seed leaves. (See Fig. 1.) These sometimes attained an abnormal size of 3 inches in length and several times the usual thickness. The size seemed to be influenced in part by the soil and in part by the nutrient solution added. These abnormally large leaves transpired very little water and tended to remain turgid as the soil dried. Dead spots appeared at the margins of the leaves and gradually increased in size and number. Wilting symptoms as shown by true leaves were sometimes totally lacking in these abnormal seed leaves.

The most common symptoms of boron deficiency were cessation of terminal growth, accompanied with small cupped-under leaves, often

somewhat chlorotic near the terminal. Growth in height was therefore restricted somewhat in proportion to the severity of the boron deficiency. Attention was first directed to the importance of boron as a result of using weak solutions that added about 5 p.p.m. of boron to the soil. This caused new growth from a lateral bud even after growth in height had entirely stopped. The new shoot usually came out at the side of the old stem after the boron was applied to the soil and then the plant would continue to make normal growth.

FIG. 1.—Extreme boron deficiency symptoms on sunflowers. Terminal buds killed. Growth practically restricted to cotyledons. Grown on sandy loam soils from the Dalles, Ore. Soil series unknown.

A mildew appeared on the sunflowers during August and September of both 1936 and 1937. It was noticed first on the seed leaves of the boron-deficient plants. In severe cases, this condition was followed by mildew on the upper leaves of the same plants. The boron-treated plants showed very little, if any, mildew at the same time that boron-deficient plants were white with the fungus.

If the non-treated plants made what appeared to be a normal growth for a time before boron deficiency symptoms appeared, there was a tendency for the stem to split. This symptom, however, was not consistent enough to be used as an indication of boron deficiency.

A shortage of moisture aids in bringing out boron deficiency symptoms. In the greenhouse, repeated partial wilting of the sunflower plants has been used to intensify symptoms. Recovery from partial wilting is complete when the plants are grown on soil to which boron has been added. Boron-deficient plants may or may not recover from similar treatment. Addition of lime to the soil growing the sunflowers also intensifies symptoms of boron deficiency. This has been observed repeatedly though no data in this regard are presented in this paper.

The sunflower shows very clear and definite symptoms of boron deficiencies; and because it can be readily grown under greenhouse conditions with ordinary labor, its use has been adopted as an indicator plant and grown on soils or in nutritive solutions. If it does not show boron deficiency symptoms within a short time, one can be reasonably sure sufficient boron is being supplied for its normal growth. If the sunflower plants show definite boron deficiency symptoms, the response of other plants should be studied since the soil may not supply sufficient boron for their requirements.

BORON DEFICIENCY SYMPTOMS IN OTHER PLANTS

In an effort to determine the reactions of other plants to a possible boron deficiency, a number of plants were grown on a soil which had produced symptoms of boron deficiency in sunflowers. On this soil beans and tomatoes showed extreme symptoms of boron deficiency. The bean leaves became chlorotic, the growth was depressed and little or no blossoming occurred, and there was no set of fruit. The first noticeable effect on the tomato plants was a reddish or bronze color of the small terminal leaves, followed by dying of both terminal leaves and buds. No blossoms were produced and the old leaves became lighter in color where boron was deficient (Fig. 2).

Turnips and radishes were not as sensitive to low levels of boron as sunflowers, beans, and tomatoes. There was a distinct difference in size of top growth in favor of the plants supplied with boron. Near the end of the experiments the turnips and radish plants became

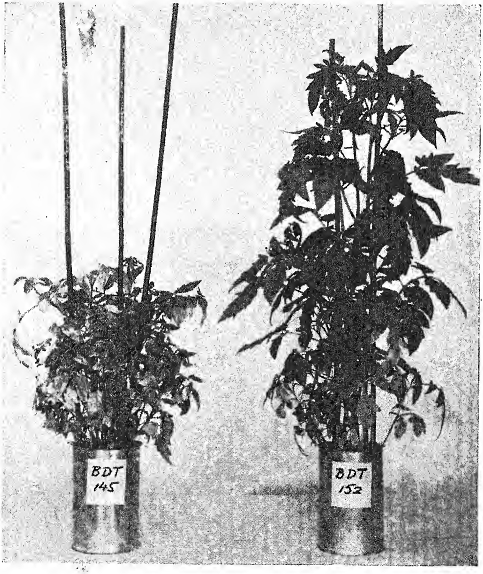

FIG. 2.—Tomatoes. Can No. 145, no boron; Can No. 152, 2½ p.p.m. boron added. Grown on Melbourne clay loam.

heavily infested with aphis and white fly. A selenium spray was used on all the plants with the result that those not treated with boron were killed. Plants treated with boron were seriously burned but rapidly overcame the injury.

Clover, vetch, peas, cabbage, and celery showed little or no response to boron in experiments of 10 weeks duration. Four ornamental greenhouse plants, poinsettia, snapdragon, asparagus fern, and forget-me-nots already rooted when the test started, also showed no response to boron applications on this soil.

Corn, oats, and barley plants showed tip burning on the leaves from an application of 2½ p.p.m. of boron to this soil. These plants seem very sensitive to excess boron. The untreated plants at first were noticeably more vigorous and of better color than the treated plants, but by the end of the experiment no difference could be noted.

Pansies were found to be very sensitive to applications of boron. The plants treated with 2½ p.p.m. of boron barely remained alive while the untreated plants were normal in appearance.

AMOUNT OF BORON USED TO CORRECT BORON DEFICIENCY

The amount of boron that could be added to the soils without causing injury to the plants was very limited and quite variable depending somewhat on the nature of the soils employed.

When 5 p.p.m. of boron were added to certain sandy soils there was some toxicity and addition of more than this amount to heavier soils proved toxic. In some cases on the heavier soils when only 1 p.p.m. was added, the supply of boron became exhausted before the experiment was completed as was indicated by the development of boron-deficiency symptoms in the plants. The application of 2½ p.p.m. of boron to the soil has in nearly all cases proved an adequate treatment and has prevented the occurrence of boron deficiency symptoms even when the plants were grown to maturity.

DISTRIBUTION OF AVAILABLE BORON IN THE SOIL PROFILE

The available boron in the soil profile was studied by using the sunflower as an indicator plant. The results varied with different soil types and somewhat with previous farm practices, particularly that which affected the humus content of the soil. Sunflowers showed boron deficiency symptoms at once when grown on samples taken at a depth of 5 and 6 feet from a Willamette silty clay loam soil located in an old fence row which probably had not been disturbed for over 30 years. No boron deficiency symptoms were visible after 30 days on the plants grown on samples of this soil taken from the upper 3 feet, but at the end of 39 days deficiency symptoms appeared on sunflowers grown on soils from the second and third feet. No abnormality was discernible in plants in the surface foot of soil at the end of the experiment. Only the surface foot of soil failed to show boron deficiency and below this depth the deficiency as indicated by sunflowers was greater with increasing depth.

In the adjoining land fruit trees have been grown with clean cultivation for 25 years preceeded by grain farming for an unknown period of years. Annual winter crops have been regularly grown in the

orchard for 25 years. On the cultivated soil boron deficiency appeared in the plants grown in the fourth, fifth, and sixth foot soon after the seed leaves appeared. The deficiency symptoms were present in the plants grown on soil samples taken from all depths at the end of 30 days. The deficiency symptoms were therefore more marked in sunflowers grown on soil samples of comparable depths from the old cultivated field than from the undisturbed soil.

This behavior was probably related to the amount of organic matter which had been returned or is present in the soil from the cultivated area and the unfarmed fence row where all growth has remained on the soil. Probably no organic materials have ever been removed from the uncultivated soil. Analysis shows 4.96% organic matter for the soil of the fence row and 3.54% for the cultivated plot, respectively, in the upper 6 inches. The average humus content to a depth of 3 feet is more than 60% greater for the fence row soil than for the cultivated soil (Table 1). In the greenhouse 50 grams of well-rotted dried manure added to 400 grams of the old cultivated soil resulted in the growth of normal plants. In all soils studied to date in the greenhouse this amount of organic matter has furnished sufficient boron so that no deficiency symptoms have appeared in sunflowers. The correction of boron deficiency by the use of manure in the field has not been demonstrated. The greater humus content of the upper 3 feet of soil in the fence row may account for less pronounced shortage of available boron.

TABLE 1.—*Humus content of cultivated and uncultivated soil, Willamette silty clay loam.*

Depth, inches	Uncultivated soil, fence row, %	Cultivated soil orchard, %	Difference, %
0– 6	4.96	3.54	1.42
6–12	4.28	2.24	2.04
12–24	3.33	1.84	1.49
24–36	1.29	0.88	0.41
Average	3.465	2.125	1.34

RATE OF GROWTH IN RELATION TO AVAILABLE BORON

The comparative availability of boron in different soil horizons can be judged in part by the rate of growth of the plants. Rate of growth was recorded by height measurements of sunflowers in the various soils with and without boron. As soon as the cotyledons were unfolded and the terminal growth with true leaves began, height measurements were made on all the plants in the different groups and repeated at approximately weekly intervals. The comparative rate of growth of plants in Aiken clay loam samples from the horizons 6 to 12 inches, the fifth, and ninth foot, all treated with complete nutrient, is given in Fig. 3.

The graph shows the different variations in boron deficiency as indicated by the rate of growth of plants in soil samples taken from these different depths. There was a very slight response to boron in

the growth of the plants where boron was added to the samples of soil taken down to and including the fifth foot. Below the fifth foot the response increased to a maximum in the ninth foot. Only three levels, the surface 6 inches, the fifth, and the ninth foot depths are shown in the graphs to simplify the diagram. The tendency was for plants in the upper horizons of Aiken clay loam soil without boron to outgrow those treated with boron during the earlier stages of growth. Later those receiving boron made the most growth. However, the difference in rate of growth between plants grown in the upper level of soil to which boron had been added and those in soil without additional boron was very small. Below the fifth foot the response to

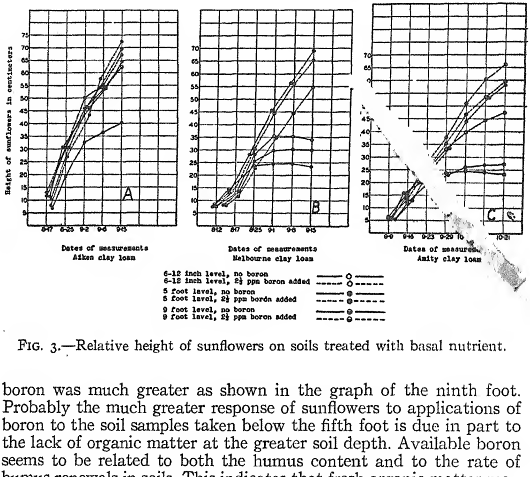

FIG. 3.—Relative height of sunflowers on soils treated with basal nutrient.

boron was much greater as shown in the graph of the ninth foot. Probably the much greater response of sunflowers to applications of boron to the soil samples taken below the fifth foot is due in part to the lack of organic matter at the greater soil depth. Available boron seems to be related to both the humus content and to the rate of humus renewals in soils. This indicates that fresh organic matter may serve as a source of boron.

With sunflowers grown in Aiken clay loam where no boron was added, mild boron deficiency symptoms were visible soon after the development of the cotyledon leaves. These became very noticeable in the levels below the fifth foot as shown in the data from the ninth foot. Above the fifth foot of soil boron deficiency was not serious until near the end of the experiment.

Basaltic soils, of which the Aiken clay loam is a representative, as a rule produce less marked symptoms of boron deficiency with the sunflower than any other soils tested from the Willamette valley of Oregon. Basaltic soils vary in the response to additions of boron

according to the type and past cultural treatments but characteristically show little response except in the lower depths.

The comparative rate of growth of sunflowers on Melbourne clay loam soil samples from different depths is shown by the graphs in Fig. 3. The plants on soils from all depths treated with basal nutrient with and without additional boron made a comparable growth only for the first 5 days. During the next 8 days plants receiving no boron and grown on soil samples taken at depths from the fifth to the tenth foot slowed down in growth. Those plants in soil from the 6 to 12 inch horizon continued their growth for another week. By that time all plants with basal nutrient but without boron had made their maximum growth while those receiving boron continued with no apparent diminution in growth rate for two more weeks or until the end of the experiment at which time many plants were beginning to bud. The difference in vigor of plants grown on soil samples from the surface 6 inches and from a depth of 10 feet in the same Melbourne clay loam soil and supplied with basal nutrient solution with and without boron is illustrated in Fig. 4. In the upper 6-inch sample without boron the plants had grown considerably taller than plants grown in the sample from the tenth foot. When, finally, the available boron was exhausted, growth ceased. The plants grown in the sample from the tenth foot ceased growth some time before. Where boron was added to comparable samples, the plants continued to grow although those in the surface sample grew more rapidly and became taller.

In Fig. 3 is also shown the height of sunflowers grown on samples of Amity silt loam receiving basal nutrient solutions with and without boron. The data of Fig. 3 indicate that the Amity silt loam is comparatively low in available boron, though not quite as low as the Melbourne clay loam. It is interesting that when boron is supplied with the basal nutrient, growth in soil from the fifth foot depth is somewhat better than growth in the surface soil under similar conditions. Even the tenth foot depth of soil when supplied with basal nutrient and boron supports nearly as good growth as the surface soils. These trials have been repeated several times with similar results.

DRY WEIGHT OF PLANTS IN RELATION TO AVAILABLE BORON

In addition to measuring the height of the plants grown in the various soil samples with and without boron and basal nutrient solution, at the end of each experiment the dry weight of the plants was determined. These data, given in Table 2, show the response of sunflower plants to boron when grown on soil samples taken from different levels. The Aiken soil shows least response in sunflower growth when treated with boron. There is practically no response in the 6 to 12 inch level or in the fifth foot. Both the Amity and Melbourne soils show marked response to boron treatments as indicated by sunflower growth. There is a response on soil samples from all depths, but a greater response on soil samples from the fifth and tenth foot levels than from the 6 to 12 inch depth. Thus, dry weight determinations fully verify the height measurements, indicating plant responses to boron.

The data of Tables 3, 4, and 5, giving dry weights of sunflowers grown on soil samples from each horizon of a 9- or 10-foot profile,

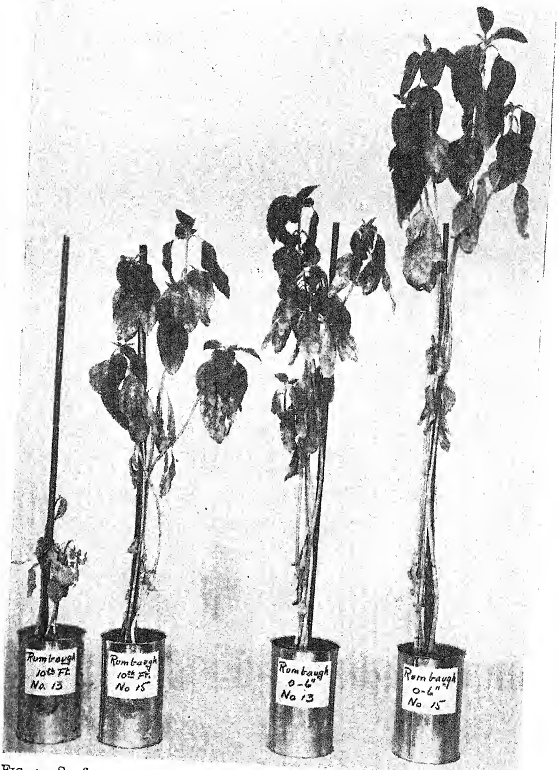

FIG. 4.—Sunflower plants on Melbourne clay loam treated with basal nutrients and boron. Cans Nos. 13, no boron added; Nos. 15, 2½ p.p.m. boron added.

indicate that the crop-producing power of the Melbourne, Aiken, and Amity soils, without nutrient or boron treatment, was about equal.

TABLE 2.—*Average dry weight in grams of single sunflower plants grown on samples of soil taken at different depths from three representative soils, all plants being supplied with a basal nutrient solution.*

Soil	Average dry weight of single plants in grams		
	Without boron	With boron	Difference due to boron
Aiken clay loam:			
6–12 inches	0.990	0.988	+0.002
5 feet	0.976	1.028	+0.052
9 feet	0.405	0.930	+0.525
Amity silt loam:			
6–12 inches	0.467	0.855	+0.388
5 feet	0.266	0.930	+0.664
10 feet	0.242	0.882	+0.640
Melbourne clay loam:			
6–12 inches	0.575	0.987	+0.412
5 feet	0.270	1.324	+1.054
10 feet	0.338	1.161	+0.823

Growth of sunflowers was also about equally good in the soil from the 0 to 6 inch and the 6 to 12 inch levels. Soil taken at any depth below 2 or 3 feet produced about equally satisfactory growth, but not as good growth as the soil from the top foot or two.

Response of sunflowers to basal nutrient was dependent upon the capacity of the soil from the different levels to supply boron. With the little growth made on untreated soils, little boron was required.

TABLE 3.—*Dry weight in grams of 10 sunflower plants (two replications of five plants each) grown on samples of Melbourne clay loam taken at different depths to which were added distilled water or basal nutrient solution with or without 2½ p.p.m. of boron.*

Depth at which soil samples were taken	Average dry weight in grams of 10 sunflower plants			
	Distilled water		Basal nutrient solution	
	No boron	2½ p.p.m. boron added	No boron	2½ p.p.m. boron added
0– 6 inches	3.460	3.265	10.295	12.230
6–12 inches	3.235	2.990	5.755	9.870
2 feet	2.695	2.540	5.625	13.340
3 feet	1.525	1.890	5.205	13.340
4 feet	1.360	1.495	2.740	13.275
5 feet	1.370	1.520	2.706	13.245
6 feet	1.295	1.775	3.193	12.795
7 feet	1.220	1.490	2.810	11.353
8 feet	1.565	1.650	2.565	13.285
9 feet	1.535	1.785	3.896	12.934
10 feet	1.450	1.450	3.385	11.610
Average weight for 10 plants	1.834	1.986	4.38	12.479

TABLE 4.—*Dry weights in grams of 10 sunflower plants (two replications of five plants each) grown in samples of Aiken clay loam taken at different depths to which were added distilled water or basal nutrient solution with or without 2½ p.p.m. boron added to the soil.*

Depth at which soil samples were taken	Average dry weight in grams of 10 sunflower plants			
	Distilled water		Basal nutrient solution	
	No boron	2½ p.p.m. boron added	No boron	2½ p.p.m. boron added
0– 6 inches	2.790	2.960	9.493	9.291
6–12 inches	2.749	3.213	9.900	9.880
2 feet	2.419	3.100	9.280	10.215
3 feet	2.073	2.360	8.110	9.855
4 feet	1.995	2.150	6.320	10.930
5 feet	2.245	2.255	9.769	10.289
6 feet	1.605	1.925	6.390	10.455
7 feet	1.405	1.760	5.535	10.400
8 feet	1.290	1.540	5.540	10.435
9 feet	1.270	1.460	4.500	9.301
Average weight for 10 plants	1.984	2.272	7.483	10.105

TABLE 5.—*Dry weight in grams of 10 sunflower plants (two replications of five plants each) grown on samples of Amity silt loam taken at different depths to which were added distilled water or basal nutrient with or without 2½ p.p.m. boron added to the soil.*

Depth at which soil samples were taken	Average dry weight in grams of 10 sunflower plants			
	Distilled water		Basal nutrient solution	
	No boron	2½ p.p.m. boron added	No boron	2½ p.p.m. boron added
0– 6 inches	2.520	2.240	5.710	9.140
6–12 inches	2.445	2.130	4.670	8.550
2 feet	1.870	1.810	3.390	9.290
3 feet	1.740	1.600	1.900	9.565
4 feet	1.550	1.720	2.320	9.355
5 feet	1.570	1.880	2.660	9.300
6 feet	1.875	2.160	2.525	10.075
7 feet	1.605	2.240	2.470	9.420
8 feet	1.720	2.170	3.155	9.515
9 feet	1.850	2.590	2.440	8.430
10 feet	1.595	2.290	2.420	8.820
Average weight of 10 plants	1.849	2.075	3.060	9.223

When nutrient was supplied, the rapid growth soon exhausted the supply of available boron in the more deficient soils or soil horizons. Only the surface 6 inches of the Melbourne soil furnished nearly an adequate amount of boron. The 6 to 12 inch and the second and third

foot depths furnished about half as much available boron as the 0 to 6 inch depth. From the fourth foot down the available boron was much lower. The Amity soil supplied half as much available boron in the 0 to 6 inch level as the Melbourne soils as indicated by plant growth. The 6 to 12 inch level was about equally as good as the 0 to 6 inch level for supplying available boron in both soils. The second and third foot levels of the Amity soil were poorer in available boron than similar depths in the Melbourne. Below the third foot the two soils were nearly equally poor in their capacity to supply available boron. The Aiken soil showed comparatively little boron deficiency even when basal nutrient was used down to the sixth foot depth. Below that depth boron deficiency was marked.

With both boron and basal nutrient supplied, all depths and all three soils produced plants relatively uniform in size. Based upon the data of Tables 3, 4, and 5, and considering the whole soil profile, the Amity soil was most deficient in available boron and the Aiken soil least deficient. The growth increases for basal nutrient without boron on the entire profile were approximately 65, 139, and 277% for the Amity, Melbourne, and Aiken soils, respectively. With boron in addition to basal nutrient, the increases over basal nutrient without boron were approximately 201, 185, and 35% for the Amity, Melbourne, and Aiken, respectively. Considering only the top 3 feet where feeding roots probably obtain most of their nutrient, the increases from basal nutrient without boron were 82, 146, and 267%, and for basal nutrient and boron over basal nutrient alone 133, 81, and 7% for the Amity, Melbourne, and Aiken soils, respectively. These data bring out the relative importance of boron in addition to basal nutrient in the three soils. Boron was nearly as important as other nutrients in Amity and Melbourne but much less important in the Aiken soil.

DISCUSSION

These studies indicate that sunflowers can be successfully used as an indicator of the level of available boron in soils. Since the sunflower is undoubtedly a heavy user of boron, the deficiency as indicated by this plant can not be taken as proof of a deficiency for all plants. But if the sunflower plants when grown on a certain soil and watered with a basal nutrient solution do not show any boron deficiency symptoms, this soil probably has plenty of available boron for most plants. The methods used in this work permit a test to be completed in 8 to 10 weeks or less and can be used to establish or eliminate boron as a probable limiting factor in plant nutrition in a given soil. By taking soil samples from definite horizons the distribution of available boron in the soil profile can be established.

Whether these data can be fully applied to field conditions, remains to be determined. Tests under greenhouse conditions with small amounts of soil may give altogether different results from those obtained in the field with large quantities of soil. This procedure has been successfully used at the suggestion of one of the authors for detecting boron deficient soils in Idaho (2). Field tests are now under way but it will require several years to investigate fully the need of

boron for nut and fruit crops. Since this work was completed, Bouquet and Powers (1, 3) have reported correction of celery crack and beet canker from the use of boron in field treatments.

Withholding water caused boron deficiency symptoms to develop more severely on the plants grown under greenhouse conditions. Under field conditions, dry seasons may make the need of boron seem more pronounced, while seasons of well-distributed, abundant rainfall will minimize the deficiency. Thus, certain seasonal conditions have a great effect on the appearance of the plants and the apparent boron deficiency.

When large amounts of fertilizers are added to field or orchard crops, the limited supply of available boron may be used up and boron deficiency symptoms will appear where they would not have been evident without the application of the fertilizers. Since the symptoms may develop at any stage of growth, crops harvested before full maturity might be less affected than those where full maturity takes place. In sunflowers, normal growth may continue until the plant is ready to bloom. A deficiency of boron at this stage of growth inhibits flower development while plants with the requisite amount of boron develop normal flowers and seed.

Boron deficiency can be expected to be more pronounced on soils that are eroded, such as the Melbourne series derived from sandstone. Erosion removes the top soil and boron deficiency is usually greater in the deep soil than in the surface horizons. Since humus and available boron seem to be associated in this study, the available boron is probably relatively limited in eroded soils in part because of diminished humus supply.

Boron deficiency as a cause of poor nutrition of apples (4) has been well established in many parts of the world, but boron deficiency as a cause of poor filling of walnut kernels has not been proved as yet. While analysis of walnut leaves from trees grown on the boron-deficient soils shows a relatively low boron content, no definite proof has yet been found that boron deficiency is concerned with poorly filled walnut kernels, possibly due to the short period for which trials have been conducted.

SUMMARY

Definite boron deficiency symptoms developed in sunflowers grown in the greenhouse on various soil types. Other plants varied widely in the development of these symptoms and in their reaction to boron applications on the same soils.

Boron deficiency can be corrected by adding 1 to 2½ p.p.m. of boron to the soil when small samples are used for growing plants in the greenhouse.

Soils long clean cultivated and low in organic matter contain less available boron than uncultivated soils of the same type. Humus depletion seems to aggravate boron deficiency and the addition of an adequate amount of compost to the soil corrects the deficiency.

Boron deficiency is shown in sunflowers by a cessation of growth of the terminal bud, reduced dry weight, and abnormal leaf characteristics.

Available boron is usually greatest in the upper 3 feet of soil. In the depths below 3 feet the shortage is often extreme.

Unless plants are supplied with available nutrients sufficient to produce good growth, boron deficiency may be over-shadowed by other deficiencies.

Adequate amounts of available basal nutrients make possible sufficient plant growth so that boron deficiencies quickly become evident.

Soils vary widely in the amount and distribution of available boron. This may be due to the origin of the soil, weathering, cultivating practices, erosions, humus supply, and other factors.

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THE BORON CONTENT OF SOME IMPORTANT FORAGE CROPS, VEGETABLES, FRUITS, AND NUTS[1]

J. S. McHargue, W. S. Hodgkiss, and E. B. Offutt[2]

THE Department of Chemistry of the Kentucky Agricultural Experiment Station has been investigating for some time the necessity of some of the so-called minor elements in the economy of plants and animals. Boron is one of the minor elements which has received attention in our laboratory to ascertain its importance as a nutrient for the growth of plants. The results obtained (1, 2)[3] showed that boron was an essential element for the growth of plants used in the experiments.

Since that time we have been interested in methods for the determination of boron contained in plant and animal tissues. Because of the rather widespread boron deficiencies reported by other investigators in certain forage crops, vegetables, fruits, and nuts, we undertook an investigation to ascertain the boron content of some of the principal forage crops, fruits, vegetables, and nuts consumed in foods in our locality. It will be observed from the tables that some of the samples were grown in rather widely separated parts of the country. The methods used are described in a previous paper by Hodgkiss (3). Most of these data were obtained by Dr. Hodgkiss using the colorimetric quinalizarin procedure.

EXPERIMENTAL DATA

The samples analyzed in the present study are arranged in natural groups in Table 1 and the boron content reported in parts per million of the moisture-free material.

A comparison of some of the results obtained by the colorimetric and spectrographic procedures are reported in Table 2.

In some of the samples there is very close agreement between the two methods of analysis, but in others the agreement is not so good. This is possibly due to several causes, one of which is the lack of a suitable salt base to which boron standards and samples can be added in order that the effect of extraneous elements in the samples will be minimized. This matter is still being investigated.

DISCUSSION OF THE RESULTS

From the foregoing results it is to be observed that there are some rather wide variations in the boron content of the different groups of plant materials analyzed.

Cereals, potatoes, and hays, in the order named, contained the smallest amounts of boron. On the other hand, with the exception of

[1]Contribution from the Department of Chemistry of the Kentucky Agricultural Experiment Station, Lexington, Ky. The investigation reported here is in connection with a project of the Kentucky Agricultural Experiment Station and is published by the permission of the Director. Also read before the Division of Agricultural and Food Chemistry of the American Chemical Society at the Cincinnati meeting in April, 1940. Received for publication June 11, 1940.

[2]Head of Department and Assistant Chemists, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 626.

TABLE 1.—*Boron content of various plant and animal materials.*

Material	Boron, p.p.m.
Cereals:	
Corn, white, Ky.	1.17 (2)*
Corn, yellow, Ky.	2.30 (3)
Wheat, Ky.	0.59 (3)
Oats, ?	1.02
Barley, Ky.	0.64
Rye, Ky.	1.50
Average	1.19
Pasture and hay crops:	
Bluegrass, Ky.	11.80
Bluegrass, Ky.	6.00
Orchard grass, Ky.	5.20
Timothy and clover mixed, Ky.	3.30
Average	6.57
Leguminous hays:	
Red clover, Ky.	31.30
Alfalfa, normal, Ky.	33.30
Alfalfa, abnormal, Ky.	47.00
Lespedeza, Ky.	18.10
Lespedeza, Ky.	20.30
Average	30.00
Vegetables:	
Potatoes, Irish, Ky.	4.43 (3)
Potatoes, sweet, tubers+boron, Ky.	4.10
Potatoes, sweet, leaves+boron, Ky.	105.00
Potatoes, sweet, leaves−boron, Ky.	4.40
Potatoes, sweet, leaves normal, Ky.	79.50
Average of tubers	4.31
Average of leaves	92.25
Turnips, Ky.	30.60
Tomatoes, red, Ky.	12.60
Tomatoes, yellow, Ky.	14.70
Carrots, roots, ?	41.00
Carrots, tops, ?	45.00
Cabbage, Florida	11.50
Celery, Florida	22.50
Lettuce, California	16.80
Spinach, Texas	31.50
Kale, Virginia	13.30

*Average of number of samples indicated.

TABLE 1.—*Continued.*

Material	Boron, p.p.m.
Vegetables:	
Beans, pinto, ?	17.10
Beans, soy, Ky	41.00
Peas, garden, ?	8.40
Average	24.45
Fruits:	
Apricots, dried, Calif	38.20
Dates, dried, Egypt	8.20
Figs, dried, Egypt	13.70
Orange, pulp and juice, Calif	11.00
Orange, peel, Calif	10.00
Orange, pulp and juice, Florida	10.40
Orange, seeds, Florida	17.70
Peaches, dried, Calif	38.20
Prunes, dried, Calif	25.10
Raisins, dried, Calif	21.40
Average	19.39
Nuts:	
Hickory nut, kernels, Ky	9.60
Hickory nut, shells, Ky	5.60
Pecan, kernels, Ga	2.60
Pecan, shells, Ga	8.20
Hazelnut, kernels, Ky	24.40
Hazelnut, shells, Ky	48.00
Walnut, kernels, Ky	15.40
Peanut, kernels, ?	17.70
Average of kernels	13.94
Average of shells	20.60
Milk:	
Cow's, Holstein, Ky	0.93
Cow's, Jersey, Ky	0.93
Mare's, Ky	1.80
Average	1.22
Egg yolk, Ky	0.60

TABLE 1.—*Concluded.*

Material	Boron, p.p.m.
Leaves of trees:	
Dogwood, Bell Co., Ky., sandy loam soil	22.5
Hickory, Laurel Co., Ky., sandy loam soil	59.0
Hickory, Bell Co., Ky., sandy loam soil	160.0
Sourwood, Laurel Co., Ky., sandy loam soil	68.0
Sourwood, Bell Co., Ky., sandy loam soil	66.0
Sweet gum, Laurel Co., Ky., sandy loam soil	19.2
Sweet gum, Fayette Co., Ky., sandy clay loam soil	29.4
Average	60.78
Miscellaneous samples:	
Acorns, pin oak, Ky	10.6
Tobacco, burley, Ky	67.0
Tobacco, dark, Ky	28.9
Tobacco, stalks, Ky	11.4
Tobacco, seed, Ky	6.1
Kelp, Pacific Coast, Calif	270.0
Average (kelp omitted)	24.8

TABLE 2.—*Boron content of various material as determined by different methods.*

Material	Boron in p.p.m.	
	Colorimetric method	Spectrographic method
Acorns (pin oak)	10.6	6.3
Alfalfa	33.5	33.0
Beans, soy	41.0	30.0
Beans, pinto	17.1	14.0
Bluegrass	11.8	8.1
Leaves, sweet gum	19.2	23.0
Leaves, hickory	160.0	155.0
Lespedeza	18.0	15.0
Orange pulp	15.0	10.4
Tobacco stalks	11.0	10.2

the sample of kelp, the leaves of the forest trees contained the largest amount of boron. Leguminous hays, tobacco, fruits, and leafy vegetables contained an intermediate amount of boron.

In the case of the leaves from forest trees there is some indication of selective absorption of larger amounts of boron by the hickory leaves than by the sourwood and dogwood leaves. All of the leaves were collected at the same time from trees that grew in the same type of sandy loam soil on Pine Mountain near Cumberland Gap in Bell County, Kentucky, and within a distance of approximately 50 feet of one another. The leaves were collected after the end of the growing season on October 13, 1939. The foliage of each tree had attained its

maximum characteristic autumnal coloration, yellow and tan in the case of the hickory, dull red for the dogwood, and brilliant red in the leaves of the sourwood. However, the sample of hickory leaves which was collected in Laurel County, Kentucky, on June 10, 1939, grew in a similar type of sandy loam soil as those in Bell County, but they contained less than one half as much boron as the latter.

Scribner (4) reports finding by spectrographic examination a number of rare elements in hickory leaves from a tree that grew on a pegmatite vein near Amelia, Virginia. These findings indicate that the mineral content of hickory leaves may vary considerably with the soil on which the trees grow.

From the results obtained for the boron content of the various materials reported in this paper it would appear that a boron deficiency is not likely to occur in animals receiving an adequate supply of any of the edible materials as food.

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CROP SEQUENCE STUDIES IN NORTHWESTERN OHIO[1]

R. M. SALTER AND J. G. LILL[2]

CROP rotation, in which cultivated crops, small grains, soybeans, and sod crops are grown in definite order, is accepted practice on farms in northwestern Ohio and considerable information has been accumulated regarding the soil-depleting or soil-conserving effects of the individual crops commonly included. It is also possible to evaluate fairly well the effects of the rotation as a whole upon soil productivity. On the other hand, there exists little published information regarding the order in which the cultivated crops and grain crops should occur in the rotation for most profitable returns. For several years, the Ohio Agricultural Experiment Station and the Division of Sugar Plant Investigations of the U. S. Dept. of Agriculture have cooperated in the experiment on the Northwestern Experiment Farm at Holgate, Ohio, designed to determine the effects of certain crops upon the crops following.

The soil in the area where this project is located is a Brookston clay, a heavy, dark-colored soil derived from calcareous glacial drift, of level topography, and considered well adapted to sugar beets, alfalfa, and corn when well tiled. The experimental area is only fairly well drained, the spacing of approximately 4 rods between lines of tile being somewhat wider than is optimum for this land. Other experiments on this farm point to poor physical condition as the chief limiting factor to high crop yields on this soil, fertilizers and even manure being relatively ineffective compared to such practices as the plowing down of deep-rooted legumes as alfalfa and sweet clover.

The number of crops that could be included in this crop sequence experiment was limited because the plan of the experiment and the plot arrangement used made it necessary that the soil preparation of all plots be done at the same time and in the same manner for the various crops. The crops used were sugar beets, corn, oats, soybeans for hay, and soybeans for seed. These crops were planted, cared for, and harvested according to ordinary farm methods. In the disposition of the crop residues, the sugar beet tops, corn stover, and soybean haulm were left on the land producing the crop while the oat straw and soybean hay were removed.

All of the crops were grown under each crop sequence condition each year in order to avoid the possibility of seasonal variations masking the effects that the individual crops might have upon the yields of the crops following. This was accomplished by growing the various crops in narrow, randomized strips in replicated blocks. The strips extended in one direction one season and were at right angles in the next season. Thus, after the first season, each crop followed it-

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self and also followed each of the other crops. Since the experiment was confined to the same area each year, the experimental crop the second season became the preparatory crop for the third season, and so on. The experiment covered the period 1935 to 1939, inclusive, giving four years' harvests for interpretation.

The annual mean yields for the individual crops, presented in Table 1, show wide variations associated with seasonal conditions and a fair level of production for all crops except sugar beets. Variability of response among the different crops to seasonal influences is shown by the fact that neither all the high yields nor all the low yields were obtained during the same season; also by the variation among crops in the relative yield fluctuations during the four year period, shown in Table 2.

TABLE 1.—*Average yield of each crop for each of the four seasons.*

Crop	1936	1937	1938	1939	Average
Sugar beets, tons	8.26	3.02	4.91	2.79	4.74
Corn, shelled, bu.	30.5	15.6	44.6	38.1	32.2
Oats, bu.	59.7	23.5	47.4	33.9	41.1
Soybean hay, tons	1.36	2.44	2.13	3.02	2.24
Soybean seed, bu.	18.9	26.1	28.1	31.2	26.1

TABLE 2.—*Variation in yield caused by seasonal factors.*

Crop	Acre-yield, 4-year average	Difference between extreme high and low yields	Difference as percentage of the mean yield
Sugar beets, tons	4.74	5.47	115.4
Corn, shelled, bu.	32.2	29.0	90.1
Oats, bu.	41.1	36.2	88.1
Soybean hay, tons	2.24	1.66	74.1
Soybean seed, bu.	26.1	12.3	47.1

In Table 3 are shown the 4-year average yields of each crop for each of the five crop sequences involved, also yield differences required for specific odds for significance. Since the soil was prepared at the same time and in the same manner for all crops, since no fertilizer was applied throughout the experiment, and since it may be assumed that the seasonal influences are largely eliminated by averaging the 4 years' results, it is believed that significant variations in the yield of individual crops represent primarily differential effects of the preceding crops.

It is evident that the preceding crop had considerable effect upon the yields of the crops other than soybean hay and soybean seed. Corn yields appeared to be most influenced by the nature of the preceding crop, oats and sugar beets showed a lesser but still marked influence, whereas soybeans, either for hay or seed, were affected little, if at all. It is also interesting to note that the soybeans showed the least fluctuation in yield associated with seasonal variations. These differences among the various crops are somewhat more evident if the variations in yield of the individual crops associated with

TABLE 3.—*The 4-year average yield of each crop for the various crop sequences.*

Crop grown	Crop grown during the previous season				
	Sugar beets	Corn	Oats	Soybean hay	Soybean seed
Sugar beets, tons	4.17	4.31	4.65	5.41	5.18
Corn, shelled, bu.	34.2	21.6	30.1	40.3	34.8
Oats, bu.	42.8	34.7	35.4	46.9	45.8
Soybean hay, tons	2.23	2.29	2.29	2.21	2.17
Soybean seed, bu.	26.0	26.5	25.7	26.0	26.2

Significance* determined for	Odds of	When difference is at least
Sugar beet yields	99 to 1	0.51 ton
Corn yields	99 to 1	2.8 bu.
Oat yields	99 to 1	3.2 bu.
Soybean hay yields	1 to 1	No significant difference
Soybean seed yields	1 to 1	No significant difference

*From statistical evaluation of individual crop summaries.

different crop sequences are stated as percentages of the respective mean yields, as is done in Table 4.

TABLE 4.—*Extreme variations in the yield of the various crops caused by the influence of the previous crop compared to the mean yields.*

Crop	Acre-yield, 4-year average	Difference between extreme high and low yields caused by crop sequence	Difference expressed as percentage of the mean yield
Sugar beets, tons	4.74	1.24	26.2
Corn, shelled, bu.	32.2	18.7	58.1
Oats, bu.	41.1	12.2	29.7
Soybean hay, tons	2.24	0.12	5.4
Soybean seed, bu.	26.1	0.8	3.1

It is of interest to note that, except for the soybean hay and soybean seed crops, the yield obtained when a particular crop followed itself were the poorest or close to the poorest obtained among the different crop sequences. This fact is emphasized by the data in Table 5

TABLE 5.—*Average yearly advantage indicated for the various crop sequences over the results obtained in continuous cropping.*

Crop	Crop grown in previous season				
	Sugar beets	Corn	Oats	Soybean hay	Soybean seed
Sugar beets, tons	0.0	0.14	0.48	1.24	1.01
Corn, shelled, bu.	12.6	0.0	8.5	18.7	13.2
Oats, bu.	7.4	−0.7	0.0	11.5	10.4
Soybean hay, tons	0.02	0.08	0.08	0.0	−0.04
Soybean seed, bu.	−0.2	0.3	−0.5	−0.2	0.0

showing the average yearly advantage for the various crop sequences over the results obtained in "continuous cropping".

It is obvious that if one were to attempt to set up a hypothetical 5-year rotation including each crop grown in this experiment, it would be impossible to include only the most advantageous sequences, since the results indicate the greatest possible advantage when corn, oats, and sugar beets each follow the soybean hay crop. It is possible, however, to choose an arrangement of crops which will give the greatest total advantage for the rotation as a whole. The following represents this most advantageous arrangement of the five crops and indicates the total 5-year advantage for the sequences employed compared to continuous cropping in each instance:

Order	Crop	5-year advantage (average annual advantage × 5)
1	Soybean hay	0.4 tons
2	Corn	93.5 bu.
3	Soybean seed	1.5 bu.
4	Sugar beets	5.0 tons
5	Oats	37.0 bu.

It should not be inferred from the foregoing that the rotation proposed might be a practical rotation for this region. In fact, such a rotation would probably result in the soil being depleted at a fairly rapid rate since it includes none of the more efficient soil-building sod legumes. It is intended merely to illustrate the usefulness of crop sequence data in planning an efficient crop rotation.

The favorable effect of soybeans upon succeeding crops in this experiment deserves mention since the results are at variance with much other data obtained elsewhere in Ohio. Although definite proof is lacking, it seems probable that the favorable effects of soybeans on this heavy clay soil, relatively well supplied with nutrients but having poor physical properties, may result from the well-known granulating effect of soybeans, whereas, on soils of lighter texture, less well supplied with nutrients, adverse effects may result from a temporary exhaustion of fertility by the soybean crop.

VARIATIONS IN THE DORMANCY OF SEEDS OF THE WILD OAT, *AVENA FATUA*[1]

E. H. Toole and F. A. Coffman[2]

IT HAS long been recognized that seeds of the common wild oat (*Avena fatua*) are characterized by dormancy, which may persist for an extended period following maturity. Zade (12)[3] and Atwood (2) have mentioned the very low germination of seed of *A. fatua* when freshly harvested and state that germinability gradually increases after the seed has been in storage for several months. Garber and Quisenberry (7) and Johnson (8) have mentioned the variability in germination of the seed from different plants. Lute (11) called attention to the regional variation in germination of seed of *A. fatua* and suggested that the generally accepted belief that wild oats may be distinguished by their dormancy at harvest is not well founded because of the almost complete lack of dormancy of some lots. Deming and Robertson (6), Larson, Harvey, and Larson (10), and Coffman and Stanton (3) conducted tests which showed that considerable dormancy is found in some varieties of the cultivated oats when freshly harvested. The latter (4) found also that the germinability of fatuoids, or the false wild oat forms occurring in cultivated varieties, appeared to be similar for that character to the varieties in which each was found.

Several workers (2, 7, 8, 11) have shown that germination of *Avena fatua* is increased by breaking the seed coat. Atwood (2) and Johnson (8) demonstrated the beneficial effect of increased oxygen concentration during germination, and Johnson (8) obtained a distinctly beneficial effect from soaking the seeds in 1 to 2% of KNO_3 for 24 hours, and some benefit from freezing the seed. However, none of these treatments has resulted in the complete or prompt germination of freshly harvested seed of *A. fatua.*

Unpublished results obtained from the study of *Avena fatua* plants in the greenhouse indicate that a marked variation existed in the promptness of germination of seed collected in different sections of the

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[2]Physiologist, Division of Fruit and Vegetable Crops and Diseases, and Agronomist, Division of Cereal Crops and Diseases, respectively. Acknowledgment is due the following for supplying wild oat (*Avena fatua*) plants for use in these experiments: Ralph W. Smith, Dickinson Substation, Dickinson, N. Dak.; W. B. Nelson and A. M. Schlehuber, Agricultural Experiment Station, Bozeman, Mont.; Glen Hartman, Agricultural Experiment Station, Laramie, Wyo.; D. W. Robertson and J. J. Curtis, Agricultural Experiment Station, Fort Collins, Colo.; Wayne M. Bever, Agricultural Experiment Station, Moscow, Idaho; Harland Stevens, Aberdeen Substation, Aberdeen, Idaho; Rollo W. Woodward, Agricultural Experiment Station, Logan, Utah; A. T. Bartel, Agricultural Experiment Station, Tucson, Ariz.; C. S. Holton, Agricultural Experiment Station, Pullman, Wash.; J. Foster Martin, Pendleton Branch Experiment Station, Pendleton, Ore.; D. D. Hill, Agricultural Experiment Station, Corvallis, Ore.; and Coit A. Suneson, University Farm, Davis, Calif.

[3]Reference by number is to "Literature Cited", p. 638.

United States. This observation prompted the securing of additional information on the comparative germination of seed from different *A. fatua* plants and from different sections. In addition to germination, some data were obtained on the morphologic characters of *A. fatua* from different areas as a further check of their variable nature.

MATERIAL AND METHODS

Through the collaboration of members of the field staff of the Division of Cereal Crops and Diseases of the Bureau of Plant Industry, and of agronomists of several state agricultural experiment stations, plants of *Avena fatua* were received in 1937 from stations in various western states. The seed was threshed by hand preparatory to testing. An attempt was made to use only plump "seed", i.e., containing well-developed caryopses, but no attempt was made to distinguish between primary and secondary kernels of the spikelet. Considerable variation existed in the maturity of the different collections, as well as in the number of seeds per plant available for testing. Some plants had failed to mature and, because of shattering, no seed was obtained from others.

Germination tests of different lots usually were begun the tenth day following collection, although there were a few exceptions owing to delay in the mails.

So far as available, 50 seeds from each collection were included in each test. The seeds were placed between several folds of moist paper toweling and kept in a thermostatically-controlled germinator for 14 days at which time the percentage germinating was recorded. After 14 days at 20° C, the seed remaining ungerminated was transferred to a refrigerator and kept at a temperature of from 3° to 5°C. The seed was protected to prevent drying out. After 2 to 4 weeks the samples were again returned to the germinator at 20° C. This treatment was not effective in breaking dormancy except with a few samples; therefore, the seeds still remaining were dried at room temperature, again moistened, and returned to 20° C. Germination tests were made at this temperature of all samples of which seed remained the following May (1938), or after 9 to 11 months' storage in the laboratory.

As the marked variability in the color of the kernels of *Avena fatua* is widely recognized and as observations indicated that considerable variability also existed in the germinability of seed from different *A. fatua* plants, a request was made for additional material, and numerous individual plant specimens grown in 1939 were received from several points in the western United States. These were examined individually and observations were recorded of the morphologic characters of the kernels. The characters studied in addition to germination were kernel size, lemma color, awn type, size and shape of the basal cavity, and the number and length of pubescence on the back of the lemma and base of the kernel.

EXPERIMENTAL RESULTS

GERMINATION TESTS

The comparative results of the germination tests for 217 individual plants made soon after collection and again after 9 to 11 months had elapsed are summarized in Table 1. When tested at 20° C, approximately 10 days after collection, the average germination of 9,064 seeds at the end of 14 days was 13.8%. Only sufficient seed remained of 115 samples for a second test. In this test, conducted 9 to 11 months

after storage of the seed in the laboratory at room temperature, the average germination was 64.5% of a total of 4,373 seeds.

The germination of the freshly collected seed varied greatly, both for the individual plants from a given locality and for groups of plants from different localities. The 89 collections from the four localities of Moscow, Idaho, Pullman, Wash., and Pendleton and Corvallis, Ore., were characterized by high dormancy. In each group of collections, the percentage of samples with no germination was high and the average germination was low. No freshly harvested sample from these four localities germinated more than 12%. The collections from Logan, Utah, in general, showed a similar high dormancy, although 3 of the 26 samples germinated 46, 70, and 72%, respectively. Among the 82 collections from the four localities, Fort Collins, Colo., Davis, Calif., Dickinson, N. Dak., and Aberdeen, Idaho, a high proportion of the samples germinated more than 50%, and a comparatively high average germination was obtained. In the group of 20 samples from Laramie, Wyo., comparatively few had a very low germination, but only one sample germinated more than 50%.

KERNEL CHARACTERS

The range in kernel characters of the plants obtained from six localities in 1939 is shown in Table 2. The number of plants from Pullman, Wash., and Tucson, Ariz., was small but previous records of more extensive investigations indicate that most of the kernel types present at Pullman are included in this list.

The data indicate a wide variability in the morphologic characters of the *Avena fatua* plants at all points. The variation was wider at some points than at others. Wide variation in size of kernel occurred at all points. All specimens from Dickinson, N. Dak., had black or brown kernels (lemmas), while those from Pendleton, Ore., were all gray. Variations from black to gray were observed among plants obtained from Bozeman, Mont., Pullman, Wash., Fort Collins, Colo., and Tucson, Ariz., and in addition a few yellow specimens were obtained from Pullman. Yellow specimens also have been collected at Fort Collins in other studies.

All florets in all samples bore twisted-geniculate awns regardless of the locality from which the plants came.

Some variation was observed in the size, shape, and prominence of the cavity or scar at the base of the lemma resulting from abscission. Plants in which the cavity was less prominent than usual were found frequently in collections from Fort Collins, Colo., and Pullman, Wash. Except for lemma color, the most widely variable character observed was pubescence on the lemma. Much variability was observed in pubescence on both the back and the base of the lemma. Less pubescence was observed on the back of lemmas from plants grown at Pendleton, Ore., than elsewhere, but wide variation in number and length of hairs on the lemmas was observed among specimens from all other points.

As to basal pubescence, wide variation occurred among plants from all points except Fort Collins, Colo., where the lemmas examined

TABLE 1.—*Germination of seed of wild oats from individual plants collected in 10 localities.*

Locality	Date collected	Total No. of seeds tested	Germination, %: In 14 days at 20° C, Average	Germination, %: In 14 days at 20° C, Range	Germination, %: Additional after 9 to 11 months varied treatments	No. of samples tested	Number of samples germinating grouped according to percentage germination in 14 days at 20° C: 0%	1–10%	11–50%	51–75%	76–100%	Retests in May, 1938: No. of samples tested	Retests: Total No. of seeds tested	Retests: Germination in 14 days at 20° C, %, Average	Retests: Germination, Range
Moscow, Idaho	June 16, 1937	1,103	0.5	0–2	0.1	24	19	5	0	0	0	13	325	13.2	0–50
Pullman, Wash.	July 30 to Aug. 6, 1937	700	0.6	0–2	6.4	14	10	4	0	0	0	13	555	64.3	18–95
Pendleton, Ore.	July 29, 1937	1,250	1.5	0–12	10.1	25	18	6	1	0	0	23	1,044	68.2	12–96
Corvallis, Ore.	July 18 and 28, 1937	1,233	2.0	0–12	18.0	26	16	8	2	0	0	19	825	56.8	12–100
Logan, Utah	July 1–24, 1937	1,282	8.4	0–72	2.4	26	18	3	3	2	0	18	425	62.6	0–100
Laramie, Wyo.	Aug. 12 and 23, 1937	636	13.1	0–54	0	20	1	6	12	1	0	2	25	92.0	87–100
Fort Collins, Colo.	July 26–27, 1937	544	44.5	0–88	2.0	14	3	2	2	5	2	9	450	95.3	64–100
Davis, Calif.	June 14–15, 1937	1,136	27.3	0–94	50.1	25	9	4	4	3	5	15	685	71.5	24–100
Dickinson, N. Dak.	Aug. 2, 1937	468	37.6	0–100*	1.3	21	2	1	10	3	5	1	9	100	—
Aberdeen, Idaho	Aug. 16, 1937	712	38.8	0–100	0.7	22	3	4	8	4	3	2	30	80.0	73–87
Totals or averages		9,064	13.8	—	—	217	99	43	42	18	15	115	4,373	64.5	—

*Two records of 100% germination are based on 2 and 8 seeds per sample.

TABLE 2.—*Variability in kernel characters of samples of Avena fatua collected in six localities in 1939.*

Locality	No. of sample plants	Lemma or kernel				Pubescence		Type of germination
		Size	Color	Awn type	Prominence of scar	Back	Base	
Dickinson, N. Dak.	9	Small to large	Black to brown	Twisted	High	Sparse to abundant	Abundant; very short to very long	Rather prompt; rather high.
Pullman, Wash.	5	Small to large	Reddish brown, gray to yellow	Twisted	High to very high	Sparse and long to abundant and very long	Abundant; very short to abundant; very long	Dormant.
Tucson, Ariz.	5	Small to intermediate	Black to gray	Twisted	High to very high	Absent to very abundant; very long	Abundant; medium long to very long	*
Fort Collins, Colo.	13	Small to large	Black to gray	Twisted	Medium to very high	Absent to sparse; very long	Very few to abundant; very short	Rather prompt; rather high.
Pendleton, Ore.	10	Medium to large	Gray	Twisted	Medium to very high	Absent	Abundant; very long to medium; very short	Dormant.
Bozeman, Mont.	15	Small to large	Black to dark gray	Twisted	Medium to very high	Sparse and long to abundant and long	Intermediate to abundant; very short	*

*Not tested.

bore short hairs only. The different plants varied greatly as to number of hairs, however.

In general, wide variability in the morphologic characters of the *Avena fatua* plants was observed among the specimens from all localities; but no correlation seems evident between dormancy and any of the plant characters studied.

DISCUSSION

Notes on the habitat of individual plants were furnished by the collectors, but no association was evident between dormancy and locality, habitat, or general growing conditions. Dormancy was high in samples grown on dry land in eastern Oregon and Washington as well as on irrigated land in Utah and under humid conditions in western Oregon, but was less pronounced in samples from Fort Collins, Colo. (irrigated), Dickinson, N. Dak. (dry land), and Davis, Calif. (semiarid).

Lute (11) has suggested that immature seeds of wild oats are more dormant and slower to after-ripen than mature seeds. Considerable difference in maturity was evident in the material used in this study, and these differences of maturity may have had some effect on the results. For example, 280 seeds collected at Laramie on August 12 germinated 5.4%, whereas 356 seeds collected in the same locality 11 days later germinated 19.1%. Collections at Corvallis were made on two dates 10 days apart and the collections at Pullman 2 to 3 weeks later than at Moscow, only a few miles distant, yet no plant from any of these collections had germinated more than 12% after being in the germinator for 14 days. It would thus appear that maturity was not an important factor in the variability of dormancy reported herein.

When the remnant seed of the samples was tested after 9 to 11 months in storage there was a marked increase in the average germination of the samples from each locality, but even after this long period a marked difference in the behavior of individual samples still was evident. From each locality some samples gave nearly complete germination, whereas others changed very little from the original tests. In general, seed from localities with high dormancy in the first test showed the lowest average germinations in later tests. Samples from Moscow gave a strikingly lower average germinations in tests following storage than did collections from Pullman, only a few miles distant. The Moscow collections were made at an earlier date and presumably were less mature than those from Pullman. It is possible that differences of maturity of seed influenced rate of after-ripening, although it had not led to a difference in germination in the original test.

No tests were made of the effect of pre-chilling freshly harvested seed before it had been put in the germinator at 20° C. After 14 days in the germinator, all samples were protected from drying and stored in a refrigerator at from 3° to 5° C for from 2 to 4 weeks. Following this they were returned to the germinator. Johnson (8) has shown that a secondary dormancy is developed in wild oats by holding the seed moist under conditions unfavorable for germination. However,

considerable additional germination occurred in many of the above-mentioned samples from Davis, Calif., and in a few of those from Corvallis, Ore. None of the samples from other points responded appreciably to this chilling.

All of the samples in these tests were dried and wetted again one or more times during the course of the experiments, yet only a few of the samples from Pendleton, Ore., and two from Pullman, Wash., gave appreciable additional germination following this procedure.

The variability in the morphologic characters of *Avena fatua* is, of course, generally recognized, although probably few fully realize its extent. The reason for this variability is unknown, but from observation by Coffman and Wiebe (5) and by Aamodt, Johnson, and Manson (1) reason exists for believing natural crossing between different *A. fatua* plants may be responsible in part. It seems most probable that *A. fatua* as found in any given locality consists of numerous strains some of which are likely to be segregating hybrids. Segregation could occur both in morphologic and physiologic characters.

The frequency of natural crossing in *Avena fatua* is not known, hence the proportion of segregating lines can not be estimated.

Johnson (9), from a study of delayed germination of *Avena fatua* ×*A. sativa*, observed that germinability is dominant over dormancy, consequently the non-dormant segregates in a hybrid population being first to germinate after maturity probably would be killed by any cultural operation or climatic factor unfavorable to the plants. Under such conditions the percentage of dormant individuals might gradually be increased in any given population.

Lute (11) showed that different collections of wild oats may differ in dormancy even after having been grown and harvested under uniform conditions.

It would seem possible that high dormancy in *Avena fatua* at Moscow, Idaho, Pullman, Wash., and Pendleton and Corvallis, Ore., might be related in some way to moisture or cultural conditions favorable to germination of the more promptly germinating strains. Those which germinate promptly are destroyed by winter weather or by cultural practices and a predominance of the more dormant types has resulted. At Corvallis, however, the winters are comparatively mild and killing would be expected only in occasional years. Conversely, dry weather prevailing in late summer and early autumn at Fort Collins, Colo., Dickinson, N. Dak., and Aberdeen, Idaho, may result in a deficiency of soil moisture and little or no germination of any form until spring. Consequently, a lower percentage of dormant types is found. At Davis, Calif., a special condition exists; fall moisture is ample there but the winters are so mild that little winter-killing results and all types would be expected to survive about equally well.

SUMMARY AND CONCLUSIONS

Individual plant samples of wild oats (*Avena fatua*) were collected in 10 localities in the western half of the United States and were tested for germination immediately and again 9 to 11 months later.

A marked difference was found in the proportion of dormant seeds of wild oats from different localities, and a wide variation in dormancy occurred among plants from any given locality.

Plants from six localities, examined for morphologic characters, were found to be more variable in some localities than in others.

There was no indication of association between dormancy and morphologic characters.

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BOOK REVIEW

GARDENING WITHOUT SOIL

By A. H. Phillips, New York: Chemical Publishing Co., Inc. 137 pages, illus. 1940. $2.

THIS little book is a brief and inexpensive collation of present information on soilless culture of plants. It is presented as a practical guide to this new subject and does it well. A brief introduction discusses the general field, and is followed by a chapter describing how plants grow. The remainder of the book is divided into discussion of water culture, of culture in mineral aggregates, of nutrient solutions, of soilless culture in practice, and of soilless culture on the farm.

In the appendix are an article by Mullard and Stoughton on "Preliminary Trials in Growing Horticultural Crops in Nutrient Solutions", a brief bibliography, and a list of soilless-culture equipment and sources of supply. (H.B.T.)

AGRONOMIC AFFAIRS

THIRTY-THIRD ANNUAL MEETING OF THE SOCIETY

THE thirty-third Annual Meeting of the American Society of Agronomy will be held in the Drake Hotel, Chicago, Ill., December 4, 5, and 6. The general program of the Society will be held on Thursday morning, December 5, when Dr. E. J. Kraus will speak on "Possible Use of Growth Substances in Agricultural Practice" and Dr. R. M. Salter on "Integrating Soils and Crops Research".

A statement regarding the program for the Crops Section appeared in the June number of the Journal. A recent communication from Dr. S. C. Salmon, Chairman of the Section, urges that all who contemplate appearing on the program submit titles and length of papers at an early date. He states also that the program committee would like to feature one or more sessions devoted to short papers of not more than 10 to 15 minutes, reporting on results of current research. It is not expected that such papers will present material conclusions, but rather that they will serve to stimulate interest and be informative with respect to new lines of research under way or new approaches to old problems. Communications regarding the Crops Section program should be addressed to Doctor Salmon, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C.

Accommodations may be had at the Drake Hotel for $3 for single rooms and $5 for double rooms. Reservations should be made directly with the hotel.

PROGRAM OF THE SOIL SCIENCE SOCIETY

THE Annual Meeting of the Soil Science Society to be held at the Drake Hotel in Chicago December 4, 5, and 6 will consist of 13 Sectional sessions, one general session, and one dinner meeting. The program for the general session will consist of four papers representing different Sections of the Society. The main speaker at the annual banquet will be Dr. E. C. Auchter, Chief of the Bureau of Plant Industry, U. S. Dept. of Agriculture.

The outline of the Sectional meetings follows:

Section I. Soil Physics.—Chairman, J. F. Lutz, North Carolina State College, Raleigh, N. C.
- Session A. Joint Program with Section IV.
  - Symposium: Interrelationship of the physical properties of soils and plant growth.
- Session B. Miscellaneous Papers.
- Session C. Joint Program with Section II.
  - Symposium: Clay minerals and base exchange.

Section II. Soil Chemistry.—Chairman, M. S. Anderson, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C.
- Session A. Miscellaneous Papers:
- Session B. Joint Program with Section IV and Crops Section.
  - Symposium: Interrelation between plant composition, soil type, and fertilization.

Session C. Joint Program with Section I.
(See Session C, Section I).

Section III.—Chairman, A. W. Hoffer, New York State Agricultural Experiment Station, Geneva, N. Y.
Sessions A and B. Miscellaneous Papers.

Section IV.—Chairman, W. H. Metzger, Kansas State College, Manhattan, Kan.
Session A. Joint Program with Section I.
(See Session A, Section I).
Session B. Miscellaneous Papers.
Session C. Joint Program with Section II and Crops Section.
(See Session B, Section II).

Section V.—Chairman, T. M. Bushnell, Purdue University, Lafayette, Ind.
Sessions A and B. Miscellaneous Papers.

Forest Soils Subsection.—Chairman, Herbert A. Lunt, Connecticut Agricultural Experiment Station, New Haven, Conn.
General papers and round table discussion.

Section VI.—Chairman, H. E. Middleton, Soil Conservation Service, U. S. Dept. of Agriculture, Washington, D. C.
Sessions A and B. Miscellaneous Papers.

The chairmen of the various Sections wish to extend their call for papers and to point out that the title of papers to be submitted for the various Sectional programs should be in their hands by September 1. The final date for the submission of abstracts of the papers is September 15. Attention is called to the detailed information on program regulations, governing papers presented before the Society, which appears on page 360 of the 1938 PROCEEDINGS.

REGIONAL GRASSLAND CONFERENCES

AT LEAST four regional technical grassland conferences have been or will be held in the United States this summer, all of which have been sponsored by the Pasture Committee of the American Society of Agronomy and in some instances have been held jointly with sectional summer meetings of the Society.

Conferences already held include the Regional Grassland Conference and Meeting of the Northeastern Section of the Society, Pennsylvania State College, State College, Pa., July 10 to 12; the Western Grassland Conference, Salt Lake City, Utah, July 15 to 17; and the Regional Grassland Conference for the Southeastern Section, Coastal Plain Experiment Station, Tifton, Ga., July 23 to 26. The fourth conference that has come to our notice is to be held at Ames, Iowa, September 11, in connection with the meeting of the Corn Belt Section of the Society at Iowa State College, September 9 to 10.

The programs follow much the same general trend, covering, first, an historical perspective; second, the economic and social impacts; and third, the research and educational needs for the development or

achievement of a grassland agriculture. In each case an effort has been made to acquaint the agricultural leaders of the region with the objectives, procedures, progress, research and educational needs, etc., of the conferences.

PROFESSOR C. B. WILLIAMS RETIRES

PROFESSOR C. B. Williams was retired from active administrative duties as head of the Department of Agronomy of the North Carolina State College on July 1. He will continue as a member of the staff, devoting his time to writing and other things.

Professor Williams has been associated with State College since it was established in 1889, graduating with the highest honors in the first class. Since then he has held a number of important positions as follows: 1893–1896 and 1897–1906, assistant chemist of the North Carolina Experiment Station; 1906–24, Head of the Department of Agronomy of the North Carolina Agricultural Experiment Station; 1926–40, Head of the Department of Agronomy, North Carolina State College; 1907–12, Director, North Carolina Experiment Station; 1913–40, Vice-Director, North Carolina Experiment Station; 1917–24, Dean of Agriculture, North Carolina State College; 1920, Chairman, Tobacco Research Committee; 1915, in charge of State Soil Survey.

In announcing Professor Williams' retirement, Dean Schaub, said in part, ". . . . I would like to state that Professor Williams has given long and invaluable service to the agriculture of North Carolina. I am sure, that we all regret that time finally brings us all to retirement age, but we are delighted that Professor Williams is still interested, vigorous, and undoubtedly has many more years of service for the state".

BORON AS A PLANT NUTRIENT

SUPPLEMENT II of a bibliography of literature on boron as a plant nutrient published and reviewed from January through December 1939, with a subject and author index, has been issued by the American Potash Institute of Washington, D. C.

The material, in mimeographed form, is arranged first by crops sub-divided by states. A second section is then divided into separate headings under boron with each sub-divided by states. The same abbreviations and system of numbering the references used in previous bibliographies from the same source have been followed.

NEWS ITEMS

DOCTOR WENDELL BARTHOLDI has been appointed to the position of assistant agronomist at the Rhode Island Agricultural Experiment Station left vacant by the death of Professor Crandall. He will have charge of the work in vegetable research at the station. Dr. Bartholdi received his B.S. degree from the University of Minnesota in 1934, the M.S. from Ohio State University in 1936, and the Ph.D. degree from the University of Minnesota in June 1940. The vegetable research program at Rhode Island consists largely of nutrition studies

with market garden crops. Dr. Bartholdi assumed his new duties on July 1.

Doctor L. A. Wolfanger, Associate Professor of Soil Geography and Land Use, Soils Section, Michigan State College, has been granted leave of absence to teach a special course for the summer in soil geography at Columbia University.

A National conference on land classification will be held at the University of Missouri, Columbia, Mo., October 10 to 12, 1940. Attention will be given to theories of land classification, soil factors in land classification, land classification for different purposes, and technics and practices in land classification. This meeting may be of interest to soil scientists, geographers, economists, foresters, geologists, grazing specialists, and others concerned with the larger aspects of land use.

The American Potash Institute, Inc., Washington, D. C., has announced the appointment of Errett Deck as its Northwest Representative. In this capacity, Mr. Deck will supervise the Institute's agricultural educational program in the states of Washington, Oregon, and Idaho, with headquarters at Puyallup, Wash. He replaces Clay A. Whybark who resigned to take a position as agronomist with Hunt Bros. Canning Company.

E. L. Pinnell, recent graduate of the University of Missouri, has been appointed part-time research assistant in corn breeding at the University of Minnesota.

Herbert Cramer has been appointed full-time research assistant at the University of Minnesota to work on corn and grasses.

Wm. J. White, in charge of the Dominion Forage Crops Laboratory at Saskatoon, Saskatchewan, Canada, is spending the summer at the University of Minnesota, completing his graduate work on the Ph.D. degree.

N. E. Jodon, Crowley, La., Rice Experiment Station, is doing graduate work at the University of Minnesota for the summer.

In June the following men received their Ph.D. degrees in Agronomy and Plant Genetics at the University of Minnesota: W. H. Leonard, Colorado State College; H. Y. Chen, Nanking, China; J. O. Culbertson, Sugar Plants, U. S. Dept. of Agriculture; Charles A. Rowles, University of Saskatchewan; and H. K. Schultz and Miss Marion Hilpert, University of Minnesota.

According to an announcement by the U. S. Dept. of Agriculture, Dr. Oswald Schreiner will act as advisor to the Chief of the Bureau of Plant Industry on soil problems connected with the work of the Bureau.

Martin Nelson, Head of the Department of Agronomy at the University of Arkansas College of Agriculture since 1908, retired effective June 30. Mr. Nelson was formerly the Dean of the College of Agriculture and since 1920 served the College as Vice-Dean. As

Professor Emeritus, Mr. Nelson's work will consist primarily of writing in the field of agronomy.

R. P. BARTHOLOMEW, formerly Associate Professor of Agronomy at the University of Arkansas, is now Head of the Department of Agronomy succeeding Martin Nelson, retired.

C. K. MCCLELLAND, formerly Assistant Professor of Agronomy, University of Arkansas, was made Associate Professor of Agronomy effective July 1.

DR. PAUL C. MANGELSDORF, Vice-Director of the Texas Agricultural Experiment Station, has been appointed Professor of Botany at Harvard University and Assistant Director of the Botanical Museum.

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EFFECT OF THE METHOD OF COMBINING TWO EARLY AND TWO LATE INBRED LINES OF CORN UPON THE YIELD AND VARIABILITY OF THE RESULTING DOUBLE CROSSES[1]

ROBERT C. ECKHARDT AND A. A. BRYAN[2]

EXPERIENCE with maize has amply demonstrated the value of certain crosses between early- and late-maturing strains for growing in the short-season areas to which the early strains are adapted. Earliness tends to be dominant in such crosses, and in some combinations where the differences in the seasonal requirements of the strains are not too large it has been possible to obtain in the hybrid particularly all of the earliness of the early parent together with much of the increased plant size and vigor of the late parent. This situation has been amply demonstrated in the past with open-pollinated varieties. It has been found to be equally true of hybrids involving inbred lines and is responsible for the present production and utilization of many commercial double crosses of this kind in some of the corn-growing areas with a relatively short growing season.

In the commercial production of such double-crossed hybrid seed corn a single cross of the two early lines may be crossed with a single cross of the two late lines, (E×E)×(L×L),[3] or two single crosses, each involving an early and a late line, may be crossed, (E×L)×(E×L). The first procedure necessitates planting the two single crosses on different dates with a resulting increase in the cost of producing the double-crossed seed. The second procedure requires two dates of planting on only a small scale for the production of the single crosses and permits the planting of both parents at the same time for the seed production of the final double cross. Because of the economic advantage of the second procedure, it is of interest to determine whether the double crosses produced by the two methods differ fundamentally in yield, earliness, variability, or other characters.

[1]Contribution from the Farm Crops Subsection, Iowa Agricultural Experiment Station, Ames, Iowa, and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, cooperating. Journal paper J682. Project 163. Received for publication June 20, 1940.

[2]Agent and former Agronomist, respectively, Division of Cereal Crops and Diseases; collaborators, Agronomy Section, Farm Crops Subsection, Iowa Agricultural Experiment Station.

[3]E = early inbred; L = late inbred.

MATERIALS AND METHODS

All of the inbred lines used in this study were developed in the cooperative corn improvement program of the Iowa Agricultural Experiment Station and the Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture. Six early-maturing inbred lines and eight late-maturing lines of maize were included in these studies (Table 1). The Four County White lines have white endosperm color, while the remaining inbreds are yellow.

Each double cross was composed of two early and two late inbred lines. Of the three possible double cross combinations among each group of four inbred lines, the (E×E)×(L×L) and one of the (E×L)×(E×L) double crosses were used.

TABLE 1.—*Inbred lines used in the studies and their parent varieties.*

Inbred line	Parent variety
Early Lines	
4Co 31	Four County White
4Co 82	Four County White
4Co 101	Four County White
US 153	U. S. Selection 133
Cl 447	Clark Yellow Dent
GK 646	Golden King
Late Lines	
I 159	Iodent
I 198	Iodent
I 233	Iodent
I 234	Iodent
L 289	Lancaster Surecrop
L 317	Lancaster Surecrop
KB 397	Krizer Bros. Yellow Dent
Os 420	Osterland Yellow Dent

The field plots were arranged in randomized blocks in 1936 and 1937. In 1938 a split plot design was used in which each pair of hybrids composed of the same four inbreds were treated as a unit in the randomization process and then the hybrids within the pair were randomized. Six replications were used in 1936 and 1937, while five replications were used in 1938. Measurements were taken in 1936 on individually tagged plants on silking date, plant height, ear height, and ear weight.[4] In addition, ear length and ear diameter were measured in 1937. Six replications involving 120 plants of each double cross were used for all of the studies of individual plant variability, except for ear weight in 1936 when only three replications totaling 60 plants were used.

EXPERIMENTAL RESULTS

The acre yields of the (E×E)×(L×L) and the (E×L)×(E×L) double crosses for 1936, 1937, and 1938 are shown in Table 2. The analysis of variance for the 3-year period shown at the bottom of the table indicates that the variance ascribed to method of combining was not significant. Similar individual analyses involving the data from each season were computed but are not reported.

[4]For greater detail see Eckhardt, R. C., and Bryan, A. A. The effect of the method of combining the four inbred lines of a double cross upon the yield and variability of the resulting hybrid. Jour. Amer. Soc. Agron., 32:347–353. 1940.

The crop season of 1936 was very hot and dry. The corn crop suffered severely through July with only 0.09 inch of rain and 14 consecutive days with temperatures of 100° F or above (July 4 to July 17). This resulted in low grain yields and high variability. Although the acre yields of the hybrids were low, they averaged 26.9 bushels as compared with 12.1 bushels for the two open-pollinated varieties Golden King and Osterland Yellow Dent. The analysis of variance for 1936 indicated that the variance ascribed to method of combining was not significant.

The season of 1937 was an excellent season for maize production at Ames, and this is reflected in yields of the double crosses. In this season there was a mean difference of 6.0 bushels in favor of the (E×E)×(L×L) combinations. The analysis of variance indicates that this difference is significant.

In 1938, as in 1936, the mean difference in yield between the (E×E)×(L×L) and the (E×L)×(E×L) double crosses was small. As in 1936, the variance ascribed to method of combining was not significant.

The data on the moisture content of the grain at harvest are summarized for the 3-year period in Table 3. Considering the 3-year averages, six of the (E×E)×(L×L) double crosses contained less moisture, one contained more moisture, and one had the same percentage of moisture as the comparable (E×L)×(E×L) double crosses. The analysis of variance shown at the bottom of the table indicates that the variance ascribed to method of combining is not significant.

The "t" tests were computed individually for the data from each season but are not reported. These tests indicated a significantly lower moisture content for the (E×E)×(L×L) double crosses in 1936 but not in 1937 and 1938. Considering the 24 individual comparisons throughout the 3-year period, in 17 of them the (E×E)×(L×L) contained less moisture and in 7 more moisture than the comparable (E×L)×(E×L) double crosses. This method of handling the data yielded a significant value for X^2.

The data on silking date are shown in Table 4. On the basis of the 3-year averages, six of the eight (E×E)×(L×L) double crosses silked earlier than the comparable (E×L)×(E×L) double crosses. The analysis of variance at the bottom of the table shows that the variance ascribed to method of combining is significant. The variances ascribed to pairs, years, and interaction of pairs×method of combining are highly significant. In 17 of the 24 individual paired comparisons the (E×E)×(L×L) double crosses silked earlier than the (E×L)×(E×L) double crosses with which they were compared. This method of analyzing the data yielded a significant value of X^2.

The plant to plant variability of the (E×E)×(L×L) and the (E×L)×(E×L) double crosses was studied with respect to silking date, plant height, ear height, ear weight, ear diameter, and ear length. An analysis of variance was computed for each character of each double cross in 1936 and 1937, the two seasons when individual plant data were taken. The sums of the "within replication" sum of squares were computed for each character studied for the double

TABLE 2.—*Yields of double crosses among early and late lines for 3-year period, 1936, 1937, and 1938.*

Strain or cross No.	Pedigree	Yield in bushels				
		1936	1937	1938	Average	
Golden King		7.9	53.6	72.5	44.7	
Osterland Yellow Dent		16.3	68.6	103.2	62.7	
Iowa Hybrid 931	(L 289×Cl 447)×(Os 420×Os 426)	24.9	80.4	97.9	67.7	
Iowa Hybrid 939	(I 205×L 289)×(Os 420×Os 426)	32.0	91.7	111.9	78.5	
3400	(4Co31×4Co82)×(I 159×L 289)	30.4	91.7	107.5	76.0	−†
3401	(4Co31×I 159)×(4Co82×L 289)	29.6	91.7	110.6	77.3	
3402	(4Co31×4Co82)×(I 159×KB 397)	27.5	90.9	116.1	78.2	+
3403	(4Co31×I 159)×(4Co82×KB 397)	28.3	87.8	112.4	76.2	
3404	(4Co31×4Co101)×(I 159×I 233)	30.0	97.4	116.4	78.3	+
3405	(4Co31×I 159)×(4Co101×I 233)	27.5	82.9	110.6	73.7	
3406	(4Co31×4Co101)×(I 233×KB 397)	32.8	90.2	116.3	79.7	+
3407	(4Co31×I 233)×(4Co101×KB 397)	32.9	81.9	112.0	75.6	
3408	(4Co31×US 153)×(I 233×L 317)	20.3	89.8	109.2	73.1	−
3409	(4Co31×I 233)×(US 153×L 317)	29.6	84.5	109.5	74.5	
3470	(4Co31×4Co82)×(I 159×I 198)	28.6	97.1	113.2	79.6	+
3471	(4Co31×I 159)×(4Co82×I 198)	32.6	90.1	114.3	79.0	
3410	(4Co82×4Co101)×(KB 397×Os 420)	33.3	85.5	109.9	76.2	−
3411	(4Co82×KB 397)×(4Co101×Os 420)	31.1	90.2	110.5	77.3	
3619	(I 234×L 289)×(Cl 447×GK 646)	16.1	78.8	108.5	67.8	+
3620	(I 234×Cl 447)×(L 289×GK 646)	16.7	64.8	113.6	65.0	
Mean yield of all entries		28.0	87.2	111.9	75.7	
Mean of (E×E)×(L×L) double crosses		27.4	90.2	112.1	76.6	
Mean of (E×L)×(E×L) double crosses		28.5	84.2	111.7	74.8	
Difference		−1.1	+6.0	+0.4	+1.8	

Source of variation	D/F	Sum of squares	Mean square	F value
Pairs of double crosses	7	687.09	98.16	8.91**
Years	2	59,556.78	29,776.39	2,703.93**
Method of combining	1	36.05	36.05	3.27
Years × method	2	111.10	55.55	5.04*
Pairs × years	14	403.25	28.80	2.62*
Pairs × method	7	100.44	14.35	1.30
Pairs × years × method	14	154.18	11.01	
Total	47	61,048.89		

*Significant.
**Highly significant.
† + indicates (E × E) × (L × L) double cross higher yielding.

TABLE 3.—*Moisture percentage of double crosses among early and late lines for 1936, 1937, and 1938.*

Strain or cross No.	Pedigree	Percentage moisture				
		1936	1937	1938	Average	
Golden King		17.7	8.3	11.0	12.3	
Osterland Yellow Dent		18.3	13.0	12.5	14.6	
Iowa Hybrid 931	(L 289×Cl 447)×(Os 420×Os 426)	15.7	11.0	11.2	12.6	
Iowa Hybrid 939	(I 205×L 289)×(Os 420×Os 426)	17.0	14.0	13.4	14.8	
3400	(4Co31×4Co82)×(I 159×L 289)	15.9	10.9	10.8	12.5	+†
3401	(4Co31×I 159)×(4Co82×L 289)	15.3	11.5	11.7	12.8	
3402	(4Co31×4Co82)×(I 159×KB 397)	16.1	11.7	12.0	13.3	+
3403	(4Co31×I 159)×(4Co82×KB 397)	17.9	11.4	13.1	14.1	
3404	(4Co31×4Co101)×(I 159×I 233)	15.7	12.4	13.6	13.9	+
3405	(4Co31×I 159)×(4Co101×I 233)	18.5	12.5	14.0	15.0	
3406	(4Co31×4Co101)×(I 233×KB 397)	15.0	11.9	13.5	13.5	+
3407	(4Co31×I 233)×(4Co101×KB 397)	15.3	12.2	13.4	13.6	
3408	(4Co31×US 153)×(I 233×L 317)	15.6	11.9	11.4	13.0	0
3409	(4Co31×I 233)×(US 153×L 317)	15.7	11.6	11.6	13.0	
3470	(4Co31×4Co82)×(I 159×I 198)	16.1	11.3	10.7	12.7	+
3471	(4Co31×I 159)×(4Co82×I 198)	16.6	11.6	11.4	13.2	
3410	(4Co82×4Co101)×(KB 397×Os 420)	15.2	11.9	13.5	13.5	−
3411	(4Co82×KB 397)×(4Co101×Os 420)	16.0	10.9	12.0	13.0	
3619	(I 234×L 289)×(Cl 447×GK 646)	13.7	10.0	9.9	11.2	+
3620	(I 234×Cl 447)×(L 289×GK 646)	16.3	8.5	10.7	11.8	
Mean of all entries		15.9	11.4	12.1	13.1	
Mean of (E×E)×(L×L) double crosses		15.4	11.5	11.9	12.9	
Mean of (E×L)×(E×L) double crosses		16.5	11.3	12.2	13.3	
Difference		+1.1	−0.2	+0.3	+0.4	

Source of variation	D/F	Sum of squares	Mean squares	F value
Pairs of double crosses	7	30.72	4.39	7.02**
Years	2	191.73	95.86	153.35**
Method of combining	1	1.69	1.69	2.70
Years × method	2	3.21	1.60	2.57
Pairs × years	14 } 35	12.39 } 21.88	.63	
Pairs × method	7	2.91		
Pairs × years × method	14	6.56		
Total	47	249.28		

**Highly significant.
† + indicates lower moisture percentage in (E × E) × (L × L) double cross.

TABLE 4.—*Mean silking data (days after June 30) of double crosses among early and late lines for 3-year period 1936, 1937, and 1938.*

Strain or cross No.	Pedigree	Days after June 30			
		1936	1937	1938	Average
Golden King		23.47	19.61	23.00	22.03
Osterland Yellow Dent		30.72	28.18	24.67	27.86
Iowa Hybrid 931	(L 289×Cl 447)×(Os 420×Os 426)	29.22	26.71	24.67	26.87
Iowa Hybrid 939	(I 205×L 289)×(Os 420×Os 426)	29.73	27.00	23.67	26.80
3400	(4Co31×4Co82)×(I 159×L 289)	26.55	25.05	24.33	25.31 +†
3401	(4Co31×I 159)×(4Co82×L 289)	30.00	26.49	24.67	27.05
3402	(4Co31×4Co82)×(I 159×KB 397)	29.43	26.88	24.33	26.88 +
3403	(4Co31×I 159)×(4Co82×KB 397)	30.72	26.52	24.67	27.80
3404	(4Co31×4Co101)×(I 159×I 233)	26.42	25.53	23.33	25.09 +
3405	(4Co31×I 159)×(4Co101×I 233)	27.81	27.64	24.67	26.70
3406	(4Co31×4Co101)×(I 233×KB 397)	26.70	24.57	22.67	24.31 −
3407	(4Co31×I 233)×(4Co101×KB 397)	25.25	22.89	23.33	23.82
3408	(4Co31×US 153)×(I 233×L 317)	29.84	26.19	24.00	26.68 −
3409	(4Co31×I 233)×(US 153×L 317)	27.32	23.48	23.00	24.60
3470	(4Co31×4Co82)×(I 159×I 198)	27.82	24.93	24.00	25.58 +
3471	(4Co31×I 159)×(4Co82×I 198)	28.72	26.86	24.67	26.75
3410	(4Co82×4Co101)×(KB 397×Os 420)	26.24	23.79	22.33	24.12 +
3411	(4Co82×KB 397)×(4Co101×Os 420)	26.96	23.29	23.00	24.42
3619	(I 234×L 289)×(Cl 447×GK 646)	27.47	24.98	24.00	25.48 +
3620	(I 234×Cl 447)×(L 289×GK 646)	29.21	26.63	25.33	27.06
Mean of all entries		27.84	25.36	23.90	25.70
Mean of (E×E)×(L×L) double crosses		27.56	25.24	23.62	25.48
Mean of (E×L)×(E×L) double crosses		28.25	25.48	24.17	25.97
Difference		+0.69	+0.24	+0.55	+0.49

Source of variation	D/F	Sum of squares	Mean square	F value
Pairs of double crosses	7	44.81	6.40	10.78**
Years	2	127.33	63.67	107.24**
Method of combining	1	3.39	3.30	5.71*
Pairs×method	7	18.05	2.58	4.34**
Pairs×years	14	11.23		
Years×method	2 } 30	.67 } 17.81	.59	
Pairs×years×method	14	5.91		
Total	47	211.39		

*Significant.
**Highly significant.
†+ indicates earlier silking date for (E×E)×(L×L) double cross.

crosses of the formula (E×E)×(L×L) and for those of the formula (E×L)×(E×L). The ratio of these terms provided an F value that was used as a measure of the relative variability of the two classes of hybrids. The F values for the characters studied are shown in Table 5.

The lower variance for the (E×E)×(L×L) double crosses in silking date was significant in 1936 and highly significant in 1937. The variances in 1936 were approximately 2.5 times as great as in 1937, presumably because of the drouth conditions in 1936.

TABLE 5.—*F values computed from the variances of the (E×L)×(E×L) and the (E×E)×(L×L) double crosses.*†

Year	Silking date	Plant height	Ear height	Ear weight	Ear diameter	Ear length
1936	1.15*	1.01	1.15*	1.21**	—	—
1937	1.26**	1.21**	1.16*	1.25**	1.14*	1.36**

*Significant (5% level).
**Highly significant (1% level).
†An F value greater than 1.00 signifies a lower variance for the (E×E)×(L×L) group.

There was no significant difference in variance between the (E×E)×(L×L) vs. (E×L)×(E×L) groups for plant height in 1936, but the lower variance for the (E×E)×(L×L) group was highly significant in 1937. The plant height variances in 1937 were about half those of 1936.

Variance for ear height was significantly lower in the (E×E)×(L×L) group in 1936 and 1937.

The lower variance for the ear weights in the (E×E)×(L×L) double crosses was highly significant in both 1936 and 1937.

The ear diameter variance for the (E×E)×(L×L) group was significantly less in 1937 than for the (E×L)×(E×L) group and the lower variance for ear length in the (E×E)×(L×L) group was highly significant.

The (E×E)×(L×L) double crosses had 18% less variance in silking date than (E×L)×(E×L) double crosses over a 2-year period and this difference was highly significant. This indicates that more uniformity in time of flowering can be gained by combining inbreds of the same relative maturity in the same single cross.

In no case was the combined variance of the (E×L)×(E×L) double crosses less than that for the (E×E)×(L×L) double crosses.

It is appreciated that on the basis of theory these differences in plant to plant variability will be reflected in the variability of the plot means of the crosses produced by the two methods of combining the lines. It is felt, however, that any influence of this sort that may have been carried over into the plot means is too minor to affect seriously the reliability of the analyses of variance reported in Tables 2, 3, and 4.

DISCUSSION

The double crosses used in these studies involved a total of six early lines and eight late lines. Three of the early lines may be assumed to be genetically similar, as they came from Four County White. Likewise, four of the late lines may be assumed to be genetic-

ally similar, as they came from Iodent. The remaining lines in each maturity group are of other varietal origin.

Six of the eight pairs of double crosses each involve two of the three lines of Four County White, namely, 4Co31, 4Co82, and 4Co101. Thus there is a certain amount of varietal influence associated with the influence of the parental differences in seasonal requirements in these crosses. The effect of varietal similarity in reducing variability has been demonstrated by the writers.[5] In four of the six pairs of hybrids involving two lines from Four County White, the combination using both Four County White lines together in one parental single cross was most productive over the 3-year period. In the other two pairs of hybrids the combination involving the two Four County White inbred lines in one parent yielded only slightly less than the other member of the pair.

Two of the eight pairs of hybrids involve inbreds from four varieties, four of them involve lines from three varieties, and the remaining two pairs of hybrids involve lines from only two varieties. The conclusions of the same writers that the higher yielding double cross involving two inbred lines from each of two varieties was usually produced by combining the two single crosses, each of which contained the two lines from the same variety, should hold for the last two cases. In both cases, Iowa Hybrid 3404 vs. 3405 and 3470 vs. 3471, the double crosses of the formula $(A \times B) \times (Y \times Z)$[6] had the highest yield.

Although a certain amount of varietal effect is confounded with the effect of differences in seasonal requirements, it is felt that the results obtained represent what may generally be expected from hybrids involving early-maturing and late-maturing lines. In most cases of this kind it would be expected that, although the lines in each maturity group might be from different varieties, they would be more similar genetically than those of the different maturity groups.

The variability studies indicate that greater uniformity in many characters can be obtained by combining the inbreds $(E \times E) \times (L \times L)$. Other things being equal, most farmers desire a uniform hybrid, and by combining the inbreds $(E \times E) \times (L \times L)$ silking date, ear height, ear length, ear diameter, and ear weight were significantly less variable than when the inbreds were combined $(E \times L) \times (E \times L)$.

It is reasonable to believe that this relationship would also hold for moisture content of ear corn at time of harvest. A uniform moisture content at harvest would enable the seedsman to dry his corn to a safe uniform level. He could be more confident that a moisture test would reveal the moisture condition of all the ears and not be an average of wet and dry corn, thus the danger of wet pockets with a consequent injury by organisms or low temperatures would be obviated.

There seem to be definite advantages in the production of superior hybrid seed corn from the practice of utilizing inbred lines of similar maturity in the same single-cross parent. The one big disadvantage of this practice arises from the fact that the resulting parental single

[5]*Op. cit.*

[6]A and B = inbreds from a variety; Y and Z = inbreds from a different variety.

crosses may differ materially in flowering date. Different dates of planting, applications of a phosphate fertilizer to the later single cross, using the earlier single cross as seed parent, or various combinations of these may be used to overcome dissimilar flowering times.

SUMMARY

Experiments were designed to test the best method of combining two early (E) and two late (L) inbred lines of maize. There were no consistent differences in yield between the (E×E)×(L×L) and the (E×L)×(E×L) double crosses.

Variances for silking date, ear height, ear weight, ear diameter, and ear length were significantly less for the (E×E)×(L×L) double crosses.

THE RESPONSE TO FERTILIZERS OF SOILS OF THE BLACKLAND PRAIRIE SECTION OF TEXAS AS DETERMINED BY THE TRIANGLE SYSTEM[1]

J. E. Adams, H. V. Jordan, and P. M. Jenkins[2]

THE Blackland prairie section of Texas includes some of the most important agricultural soils of the state. An outline of the area, which covers approximately 11,000,000 acres, is shown in Fig. 1. Although complete descriptions of the soils used in this work have been given by Carter (1),[3] the principal characteristics are given here as of importance to the response they show to fertilizers.

The soils of the Houston series are dominant in the area. They are productive, brown to black, highly colloidal clays calcareous throughout the profile, and with a granular surface layer. The eastern margin of the section is composed of soils of the Wilson and Crockett series. These soils vary from very fine sandy loams to clays in texture, gray to black in color, and they are moderately acid to neutral in the upper layers. The Wilson soils have dense, compact subsoils, with the surface soil tending to crust, and in general are not as productive as those of the Houston series.

Within certain areas of Houston black clay of smooth topography the soil retains the physical characters of the Houston, but it is not calcareous in the upper horizons. This latter feature makes such areas comparable with the Wilson rather than with the Houston series. Although such areas are not extensive, they have been classified in recent years as of the Hunt series. Areas of this soil have been mapped in Hunt County (7).

The variations in texture, reaction, and productivity between the soils of the Houston and the Wilson series are reflected in their chemical composition. Fraps and Fudge (2) have shown that Houston black clay, as compared with Wilson clay loam, contains 0.125 vs. 0.105% total nitrogen; 0.081 vs. 0.048% total P_2O_5; and 0.94 vs. 0.82% total K_2O. The active P_2O_5 content of the Houston is 109 p.p.m. as compared with 38 p.p.m. for the Wilson soil. The active K_2O is also greater in concentration for the Houston black clay, the values being 317 vs. 216 p.p.m. These data for the surface horizons indicate that the Houston soil is the more productive. Although no chemical data are shown for the Hunt soils, they would appear to be intermediate in fertility.

EXPERIMENTAL

Few data were available regarding the response of these soils to fertilizers when these experiments were begun in 1928. The experi-

[1]Contribution from the Division of Soil Fertility Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication June 3, 1940.

[2]Soil Technologist in Charge of the Soil Fertility Cotton Root-Rot Investigations at Austin, Texas; Associate Soil Technologist, and Assistant Agricultural Aid, respectively. The work was under the general supervision of J. J. Skinner, in charge of cotton soil and fertilizer investigations.

[3]Numbers in parenthesis refer to "Literature Cited", p. 663.

FIG. 1.—Outline of the Blackland prairie section of Texas. The dark areas represent the soils of the Wilson and Crockett series and the light show those of the Houston series.

ments were located on representative areas of Wilson clay loam, Hunt clay, and Houston black clay at various points in the Blackland section. The triangle system, as adapted to fertilizer investigations by Schreiner and Skinner (5), was used in these tests. This particular design allows comparisons among 21 fertilizers each of which carries 15% total plant food, as shown in Fig. 2. All 21 of the ratios were used in the experiments conducted on Wilson clay loam, while selected ratios representing key points in the triangle, namely, Nos. 1, 5, 8, 9, 12, 13, 14, 16, and 21, were used on the Hunt and Houston soils. In most cases the fields were in cotton for several years previous to the beginning of the experiments.

In all experiments previous to 1931 the fertilizers were applied in freshly opened furrows and bedded on at least 10 days before plant-

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                                  N

                                  21
                                15-0-0
                                 /  \
                            15  ___  20
                          12-3-0   12-0-3
                           /  \     /  \
                       10  ___  14  ___  19
                     9-6-0    9-3-3    9-0-6
                      /  \     /  \     /  \
                  6  ___  9  ___  13  ___  18
                6-9-0   6-6-3   6-3-6    6-0-9
                 /  \    /  \    /  \    /  \
             3  ___  5  ___  8  ___  12  ___  17
          3-12-0   3-9-3   3-6-6   3-3-9   3-0-12
           /  \    /  \    /  \    /  \    /  \
P2O5   1  ___  2  ___  4  ___  7  ___  11  ___  16     K2O
    0-15-0  0-12-3  0-9-6   0-6-9  0-3-12  0-0-15
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FIG. 2.—Triangular diagram showing the 21 fertilizers, each containing a total of 15% plant food. The upper figure is the triangle number and the lower figure the fertilizer analysis.

ing. The applications were simultaneous with planting in the later experiments, using a combination distributor-planter. No side applications to the growing cotton were made.

Experiments to be continued for a period of years have been initiated since 1935. The Latin square and other randomized plat designs have been used to test fertilizers indicated for these soils by the triangle tests. Data published for the Wilson soil (3, 4) and current data for the other soils confirm those secured by the earlier work here reported.

RESULTS

ON HOUSTON BLACK CLAY SOIL

Experiments were conducted at six locations during the period 1929 to 1935. The period for a particular test varied from two to four years. The plat treatments were the same from year to year and cotton was grown each year. Averages of the data for 20 individual tests are available for study. The rate of application was 600 pounds per acre for each of the nine selected analyses.

The average increases in yield of seed cotton per acre are given in Fig. 3. These were obtained where the average yield of unfertilized cotton was 604 pounds per acre. Of the single elements, nitrogen gave the best increase. This increase was 122 pounds as compared with 19 pounds for potash, 0–0–15, and 17 pounds for phosphate, 0–15–0. The

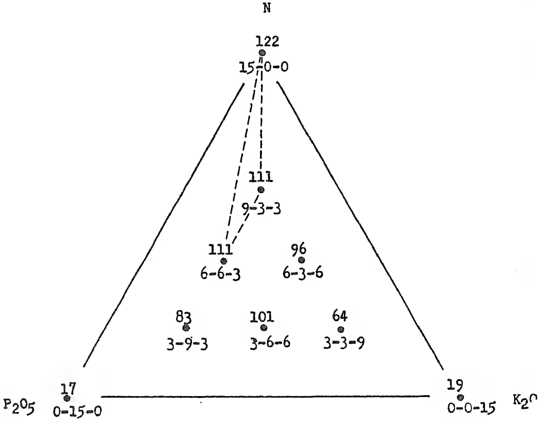

FIG. 3.—Average increases in yields of seed cotton in pounds per acre for the nine selected fertilizers used on Houston black clay soil. The three ratios producing the largest increases are connected by a broken line. The average analysis is 10–3–2.

complete fertilizers, 9–3–3 and 6–6–3, gave increases of 111 pounds each. The general area of the triangle in which maximum increases were obtained is shown by connecting the locations of the 15–0–0, 9–3–3, and 6–6–3 ratios, following the method used by Skinner (6). The average analysis of these three fertilizers is 10–3–2.

The 15–0–0 fertilizer gave the largest increase in 6 of the 20 experiments; the 9–3–3 in 5; the 6–3–6 in 4; the 6–6–3 in 3; and the 3–6–6 in 2.

ON HUNT CLAY SOIL

These experiments were conducted at the U. S. Cotton Field Station, Greenville, Texas, in Hunt County.[4] One field was used from 1928 to 1931 and another from 1932 to 1936. The nine fertilizers used on the Houston soil were also used in these tests on the Hunt clay. The fertilizer was applied at the rate of 600 pounds per acre.

The average increases, which are given as Fig. 4, were obtained where the average yield of unfertilized cotton was 493 pounds of seed

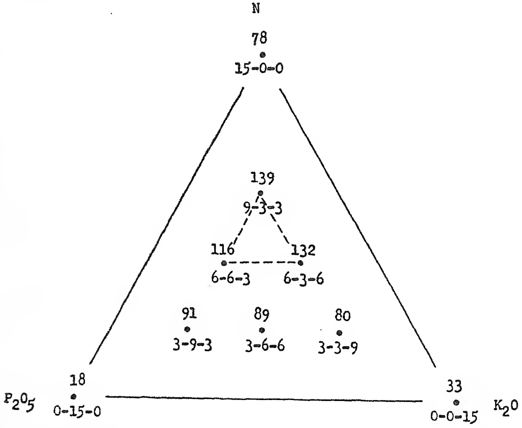

FIG. 4.—Average increases in yields of seed cotton in pounds per acre for the nine selected fertilizers used on Hunt clay soil. The three ratios producing the largest increases are connected by a broken line. The average analysis is 7–4–4.

cotton per acre. Nitrogen alone, as compared with phosphate and potash alone, gave the largest increase, as was the case for Houston black clay. The average increase due to nitrogen was 78 pounds which

[4]Acknowledgment is made of the cooperation of the staff of the U. S. Cotton Field Station, Greenville, Texas, under the supervision of Mr. H. C. McNamara, Superintendent of the Station during the period of the experiment.

is to be compared with 122 for the Houston. The three highest yielding ratios were the 9–3–3, 6–3–6, and 6–6–3. This area, representing the maximum increase, is shown as the small triangle in Fig. 4. The average of the three ratios is 7–4–4 which shows a lowered nitrogen requirement for the Hunt clay as compared to the comparable average of 10–3–2 for the Houston black clay.

In the nine years of this experiment the 9–3–3 ratio was most effective in five years, the 6–6–3 in two, and the 3–6–6 and 6–3–6 ratios in one year each.

ON WILSON CLAY LOAM SOIL

Two locations in Hunt County were used for the experiments on the Wilson soil. One field was on the farm of Richard Craig, near Campbell, and was used from 1928 to 1931. The other was on the farm of A. K. Foster, near Greenville, and was used during 1932 and 1933. The 21 fertilizers of the triangle were applied at the rate of 600 pounds in the four-year test and 900 pounds in the two-year test, giving an average application of 700 pounds per acre.

The average yield without fertilizer was 360 pounds of seed cotton per acre. The average increases given in Fig. 5 show that phosphate alone was superior to nitrogen, the increases being 208 and 136 pounds, respectively. Potash, 0–0–15, decreased the yield.

Using all 21 fertilizers, it is seen that the 6–9–0 fertilizer gave the highest average increase. It also gave the highest increase in three of six trials, with 6–6–3, 3–9–3, and 0–15–0 each superior in one year. The 6–9–0 fertilizer was not used, however, on the Houston and Hunt soils. Among the nine ratios common to all experiments, namely, Nos. 1, 5, 8, 9, 12, 13, 14, 16, and 21, the 6–6–3, 3–9–3, and 6–3–6 were the ratios producing the largest increases. The average of the three analyses is 5–6–4. The 5–6–4 analysis is to be compared with the 7–4–4 for Hunt clay and 10–3–2 for the Houston black clay.

DISCUSSION

The comparative productivity of Houston black clay, Hunt clay, and Wilson clay loam soils is reflected in the yields of seed cotton from representative unfertilized plats. The yields were 604, 493, and 360 pounds per acre, respectively. The response of these soils to fertilizers is represented by average increases of the three best of nine fertilizers common to all experiments. The increases are 115, 129, and 244 pounds per acre for the Houston, Hunt, and Wilson soils, respectively. The Hunt clay is intermediate in native productivity with respect to the Houston black clay and Wilson clay loam, also intermediate in response to fertilizers. The increase on Wilson clay loam soil was obtained with an average application of 700 pounds per acre, while the Houston and Hunt soils received 600 pounds of fertilizer per acre.

Not only are there differences in productivity and response to fertilizers among the three soils, but also differences in the kind of fertilizer needed. The dominant need of the Houston soil is for nitrogen, that for the Wilson is phosphate, while the Hunt soil again occupies an intermediate position.

While the largest yields on Wilson clay loam were obtained with a fertilizer in which the content of P_2O_5 exceeds that of nitrogen, other experiments (3, 4) have demonstrated that such fertilizers tend to increase mortality from the cotton root-rot disease. High-nitrogen fertilizers have the opposite effect. For this reason, where root-rot is a factor on Wilson clay loam, a fertilizer such as the 9–3–3 would be preferable. The 9–3–3 ratio has given good increases in yield and has shown some measure of root-rot control as well.

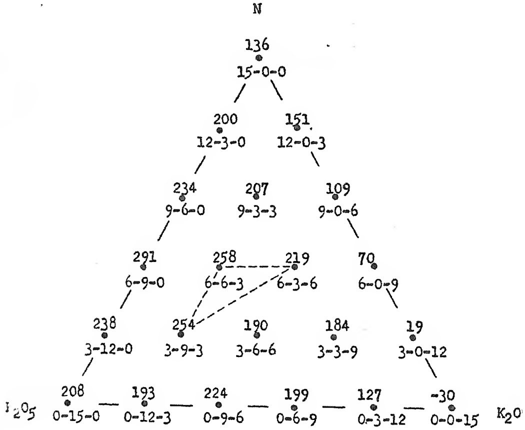

FIG. 5.—Average increases in yields of seed cotton in pounds per acre for 21 fertilizers used on Wilson clay loam soil. For comparison with data for the Houston and Hunt soils the broken line connects the three best fertilizers of the nine selected ratios common in experiments on the three soils. The average analysis is 5–6–4.

The 10–3–2 ratio indicated for Houston black clay is unusual for cotton production and demonstrates the value of the triangle system in orienting fertilizer work.

The nine key ratios can be used to indicate the general area of the triangle in which maximum increases are to be obtained for a particular rate of fertilizer application. The information is more complete, of course, if data are available for all 21 fertilizers. This is shown for the Wilson clay loam. The 12 additional fertilizers used on this soil included one, the 6–9–0, which gave the largest increase in yield. The absence of potash in this 6–9–0 ratio indicates that the use of the full triangle would have changed the values, i.e., 10–3–2, 7–4–4, and 5–6–4, by lowering the potash contents. The relative abundance of

active potash in the Houston and Wilson soils, as reported by Fraps and Fudge (2), also supports this interpretation.

SUMMARY

The effects of fertilizers on the production of cotton are reported for 20 experiments on Houston black clay soil, 9 on Hunt clay, and 6 on Wilson clay loam. These are three of the cotton soils of the Blackland prairie section of Texas. The average yields of unfertilized plats were 604, 493, and 360 pounds of seed cotton per acre for the three soils, respectively.

Using nine key ratios according to the triangle system, the maximum increase in yield, as an average of the three best fertilizers for each soil, was 115 pounds for the Houston, 129 for the Hunt, and 244 for the Wilson soil. The average analysis of the three best fertilizers was 10–3–2 for the Houston, 7–4–4 for the Hunt, and 5–6–4 for the Wilson soil. Additional information on the Wilson soil indicates that the potash content probably could be reduced somewhat for each of the soils.

The study shows gradients in fertility and response to fertilizers as one changes from Houston to Hunt to Wilson soils. The triangle system has been particularly effective in obtaining orienting information concerning the fertilizer needs of the soils of the section. The Latin square and other approved field experimental designs have been used since 1935 to test the fertilizers indicated by the triangle experiments as of greatest importance for an understanding of the fertility of these soils. The data confirm those secured by the triangle system.

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SOLUTION CONCENTRATION AS A POSSIBLE FACTOR INFLUENCING SOIL AGGREGATION[1]

H. E. MYERS AND H. E. JONES[2]

THAT crop plants exert a differential influence on soil tilth has long been recognized and some progress has been made in the elucidation of factors responsible for structural changes resulting from plant growth. Specific factors which have been suggested as contributing to changes in tilth as a result of the growth of crops include root pressure, desiccation, changes in quantity and quality of organic matter, microbial activity, and salt concentration of the soil solution. The possible relation of changes in the salt concentration of the soil solution, especially that of nitrate nitrogen resulting from the microbial decomposition of plant residues, has been suggested by Conrad (1)[3] as an explanation for the differential influence of organic materials on the tilth of soils. He presented evidence which indicates that a decrease in colloidal dispersion accompanies an increase in the concentration of the solution and *vice versa.*

While working in the soils laboratory at the University of Missouri on another phase of the general problem of factors influencing stable aggregate formation, the senior author (2) observed that the addition of calcium sulfate to a sand-colloid mixture in an amount such that the calcium was equivalent to the exchange capacity of the colloid did not increase the percentage of water-stable aggregates synthesized. The experiments reported herein were carried out in order to investigate the influence of salts at greater concentrations on aggregate formation and stability.

MATERIALS AND METHODS

The colloid used was isolated from the heavy B horizon of a soil on the Kansas State College campus. It was transformed to a hydrogen system by electrodialysis. The pulverized clay was a sample from the B horizon of the same soil crushed to pass a 0.105-mm U. S. standard sieve. The quartz sand was also ground to pass a 0.105-mm sieve. It was then digested in concentrated hydrochloric acid and finally washed free of chlorides with distilled water.

Synthesized aggregates were prepared by evaporating either a suspension of 2 grams of H-colloid and 4 grams of quartz sand or a mixture of 5 grams of finely pulverized clay and 5 grams of quartz sand in the presence of varying concentrations of calcium nitrate and sucrose on a steam bath. As the systems approached dryness they were agitated constantly. In all experiments with synthesized aggregates the mixtures were evaporated as quickly as possible after the sucrose and calcium nitrate were added. Usually about 8 hours were required for the drying process. The temperature of the suspension during the period of evaporation was about 75° to 80° C. The heavy clay-quartz sand suspensions with the treatments added were shaken mechanically for 15 minutes previous to being placed on the steam bath.

[1]Contribution No. 305, Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kan. Received for publication June 11, 1940.

[2]Associate Professor of Soils and Student Assistant, respectively. Suggestions concerning the statistical study of the data were made by H. H. Laude.

[3]Figures in parenthesis refer to "Literature Cited", p. 668.

The natural soil aggregates used were from the A horizon of the Nuckolls silt loam from the agronomy farm. The soil was air dried and then crushed to pass a 4-mm U. S. standard sieve. Treatments were applied in solution to uniform 50-gram samples after which they stood in the laboratory for one week without further addition of water. An equal quantity of distilled water was applied to the untreated samples. Enough water was added to moisten the samples completely. The experiments were completed before the publication of the paper by Waksman and Martin (5) indicating the marked influence of micro-organisms on soil aggregation; therefore, no effort was made to control the microbial population.

The degree of aggregation was determined by wet sieving in distilled water using only the 0.105-mm sieve for the synthetic aggregates, but the 4.0-, 2.0-, and 0.105-mm sieves were used for the natural soil aggregates. The 0.105-mm sieve was selected both because it had been used in previous studies (2) and because all the materials used in the preparation of the synthetic aggregates were either dispersed colloids or substances ground fine enough to pass this size sieve; therefore, all material retained on this screen after wet sieving constituted water-stable synthesized aggregates. The sieves were moved at the rate of 30 strokes per minute through a distance of about 2 inches. The wash water was changed after each washing. All samples were dried uniformly before proceeding with the analysis.

RESULTS AND DISCUSSION

SYNTHESIS OF AGGREGATES

The effect of both sucrose and calcium nitrate on the synthesis of aggregates from both pulverized clay-quartz and H-colloid-quartz systems is shown in Table 1. The data in the third column of figures are also included in the second column wherever possible. The samples were run in groups of three for each treatment. Since the results of only three replications for the 4,000-pound rate are available, they are placed in column III along with the corresponding results from the same run for the other samples. The aggregates were washed for 15 minutes.

To test the significance of the differences between treatments, the data were studied statistically using analysis of variance (4). The results indicate no significant change in aggregation as a result of the treatments since the ratios of the mean squares (between treatments divided by the within treatments) or F values for each column of data were all below the F values required for a 5% level of significance. The standard error of the difference between two mean readings of replicated treatments shown in the table leads essentially to the same conclusion.

While the differences resulting from treatment are not statistically significant, an inspection of the data reveals a few trends that may be of some importance. There seems to be no tendency for either calcium nitrate or sucrose at rates of 1,000 or 2,000 pounds per 2,000,000 pounds to increase consistently the degree of aggregation of the materials used. The data for the calcium nitrate even suggest that possibly this salt interferes to a limited extent with the formation of water-stable aggregates. Excluding the data in column III, which are included in column II, the salt decreased the degree of aggregation six out of six times for rates of 1,000 and 2,000 pounds.

TABLE 1.—*Influence of sucrose and calcium nitrate on the synthesis of aggregates.*

Treatment*	Average percentage of original sample retained on 0.105-mm sieve			
	I Pulverized clay-quartz sand aggregates, av. of 6 samples†	II H-colloid-quartz sand aggregates, av. of 9 samples†	III H-colloid-quartz sand aggregates, av. of 3 samples†	IV H-colloid-quartz sand aggregates, av. of 9 samples‡
Untreated	41.3§	90.2	90.1	73.6
1,000 lbs. sucrose	36.9	88.9	90.2	74.6
2,000 lbs. sucrose	46.3	88.0§	87.5§	72.4
4,000 lbs. sucrose	—	—	95.2	76.1
1,000 lbs. calcium nitrate	31.6	85.3	90.0	68.8
2,000 lbs. calcium nitrate	33.6	87.3	83.8	70.6
4,000 lbs. calcium nitrate	—	—	93.0	78.9§
Ratio of mean squares, F values	0.99	1.11	1.47	1.02
F value required for 5% level of significance	2.78	2.61	2.92	2.27
Standard error of difference between 2 mean readings of replicated treatments	8.37	2.45	5.0	4.69

*Rate of application as pounds per 2,000,000 pounds dry material.
†Not moistened previous to analysis.
‡Moistened previous to analysis.
§Average of one less sample than the indicated number.

The 4,000-pound rate for both sucrose and calcium nitrate tended to increase slightly the degree of aggregation in all four cases. Since the rates at which the calcium nitrate was used are larger than the variation to be expected in the nitrate concentration of a solution of a normal soil, it appears that an increase in the concentration of the soil solution due to biological activity would not directly favor an increased percentage of water-stable aggregates. Recent data by Peele (3) indicate no increase in the degree of aggregation as a result of increasing the concentration of the soil solution with inorganic salts. That the concentration of the soil solution through its influence on root growth might be a factor in aggregate formation is within the realm of possibility.

While it might be possible for these dissolved materials to influence the stability of the aggregate cement, it should be recognized that calcium nitrate and sucrose are not water-resistant cements. In the experiments conducted to obtain the data in Table 1, little opportunity was given for microbial decomposition of the added sugar since the samples were set on a steam bath after all the systems were prepared. However, since 1 to 1½ hours were usually required to set up the mixtures, some decomposition probably did occur before the systems were placed on the steam bath. It is interesting to note that

for equal rates of application the sucrose caused a slightly higher degree of aggregation than did the calcium nitrate. The only exception to this generalization is for the 4,000-pound rate in the H-colloid-quartz system moistened before the analysis.

It is also interesting to note that while moistening previous to analysis resulted in a lower percentage of retained material than when the samples were unmoistened, the relative differences between treatments remained nearly the same.

STABILITY OF NATURAL SOIL AGGREGATES

The influence of sucrose and calcium nitrate at various rates on the stability of naturally occurring soil aggregates is shown by the data presented in Table 2. The aggregates were washed for 30 minutes. The differences between treatments are small, but each treatment did increase slightly the percentage of aggregated material coarser than 0.105 mm. The percentage retained on each of the 4-mm and the 2-mm sieves was always less than 0.2. Statistical analysis, using analysis of variance, indicates that the differences between treatments are insignificant. The ratio of the mean squares (between treatments divided by the within treatments) was 0.36, while for a 5% level of significance a ratio of at least 2.76 is required. Likewise the standard error of the difference between two mean readings of replicated treatments indicates no significant difference from treatment. The slight increase in the degree of aggregation as a result of both sucrose and calcium nitrate additions possibly may be explained on the basis of increased microbial activity since the samples were moistened and then left uncovered and undisturbed in the laboratory for one week. A study of other samples handled in a similar manner indicated that after 8 hours the material had returned to a state of near air dryness.

TABLE 2.—*Influence of sucrose and calcium nitrate on the stability of natural soil aggregates.*

Treatment*	Percentage of original sample coarser than 0.105 mm, av. of 6 samples
Untreated	31.38
500 pounds sucrose	35.48
1,000 pounds sucrose	33.82
500 pounds calcium nitrate	33.26
1,000 pounds calcium nitrate	34.22
Ratio of mean squares, F value	0.36
F value required for 5% level of significance	2.76
Standard error of difference between 2 mean readings of replicated treatments	3.7

*Rate of application as pounds per 2,000,000 pounds dry material.

CONCLUSIONS

The data presented suggest that the direct effect of both sucrose and calcium nitrate at the concentrations of 500 to 2,000 p.p.m. is to cause no significant improvement either in the synthesis of aggregates

or in the stability of naturally occurring soil aggregates. This does not preclude the possibility of an indirect favorable effect as a result of stimulated plant growth or increased microbial activity over a longer period of time.

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SAGEBRUSH-GRASS RANGE SAMPLING STUDIES: SIZE AND STRUCTURE OF SAMPLING UNIT[1]

Joseph F. Pechanec and George Stewart[2]

SAMPLING is an ever-existent problem in range research. The evaluation of the effect of experimental range practices on range forage production, the determination of the extent to which vicissitudes of climate influence plant growth, and studies of relationships between plant cover and intensity of erosion require measurement of vegetation. But it is seldom economically possible or practically desirable to observe, measure, or harvest the herbage from every plant on a range area. Usually some method of sampling is resorted to whereby data taken on a small fraction of the area are assumed to represent the whole. From these data are derived the mean or average ($\bar{x}$) as an estimate of the true area mean, and the standard deviation (s) as an estimate of population variability. Only rarely do either of these two estimates coincide with the true value. Provided that both estimates are representative, however, the standard error of the mean, $s/\sqrt{n}$, furnishes the necessary information for determining the probable range of difference between the true mean and the estimated mean, that is, the sampling error.

Theoretically, sampling error may be used to set up fiducial limits (7, pp. 200–1), (14, p. 62)[3] within which the true mean might lie. Thus used, odds would be 19 to 1 (fiducial probability, 95%) that the population mean lies between the 5% limits, or that there are only 5 chances in 100 that it will fall beyond these limits. The unbiased estimate of the standard deviation is additionally useful for predicting the approximate sampling percentage needed on other similar areas to secure a mean with an allowable range of error.

In any study of sampling two aspects must be considered, *viz.*, representativeness and accuracy. Statistically, a sample may be considered as representative if estimates derived from the sample values tend in repeated samplings to give the corresponding population values (2). This representativeness is attained only when each individual of the population is given an even chance of being included in the sample. Accuracy of sampling is affected by method of sampling unit placement, by size and structure of the sampling unit, and by sampling percentage.

Efficient prosecution of range investigations depends on both representativeness and accuracy of sampling. Value of data from well-designed experiments may be seriously impaired by inadequate sampling intensities; costs of sampling may be increased unnecessarily by inefficient plot size or structure, or through lack of care in planning; or the validity of conclusions may be subject to question if the estimates lack representativeness.

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[1]Contribution from the Intermountain Forest and Range Experiment Station, U. S. Forest Service, Ogden, Utah. This study was conducted in cooperation with the Bureau of Animal Industry, U. S. Dept. of Agriculture, at the U. S. Sheep Experiment Station, Dubois, Idaho. Received for publication June 11, 1940.

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[3]Numbers in parentheses refer to "Literature Cited", p. 682.

Much has been learned of the conditions necessary to secure representative and accurate samples. Wishart (16) and Wishart and Sanders (17) have discussed the general problem of sampling for field agriculture. Christidis (1) dealt intensively with shape of plot as an independent factor affecting plot variability. Hudson (11), in population studies of wheat, considered size and shape of sampling unit, restriction of randomization, and other pertinent problems. Comprehensive treatments of the use of analysis of variance for extracting the maximum amount of information from results of sampling have been offered by Yates and Zacopanay (19), and Cochran (2). Cochran's treatise presents the application of clear-cut formulae to results from a single method of sampling to extract information regarding the relative precision of various alternative sampling methods.

In contrast to the sampling advances of agricultural experimentation, no great specific progress has been made relevant to problems of sampling native vegetation. Davies (6) made studies on the natural pasture lands of Australia. Hanson's (9) work on the mixed prairie vegetation of North Dakota is the only available study specifically applicable to western range lands.

It was the purpose of this investigation to conduct a study of sampling, specifically with reference to size and shape of sampling unit, utilizing the principles evolved in agricultural investigations, and testing their applicability to data from the important native sagebrush-grass range type of southeastern Idaho.

EXPERIMENTAL PROCEDURE

Total herbage-yield data of arrowleaf balsamroot (*Balsamorhiza sagittata*) and tapertip hawksbeard (*Crepis acuminata*), secured on an area of native sagebrush-grass range at the U. S. Sheep Experiment Station, Dubois, Idaho, were used for this study. A rectangular area, 100 by 160 feet, slightly less than 3/8 acre, was subdivided into 640 plots, each 5 feet square, the plots being delineated by tightly stretched wire.

In the spring of 1938, before growth began, all accumulated dead herbage was removed from the area. Then in June 1938, at the height of herbage production, herbage on each 5- by 5-foot plot was clipped by hand at the ground level, placed in individual sacks, air-dried, and weighed.

Herbage yield data of each of the two species were used to construct tabular charts showing the yields on the area by each 25-square-foot plot. Using these charts of yields, the efficiency of various sampling unit sizes and shapes was tested, and the value of some sampling methods explored.

Methods of statistical analysis used are those presented by Fisher (8) and Snedecor (14). Terminology[4] is that used by Cochran (2), Hudson (11), and Wishart and Sanders (17).

[4]To sample the yield of a plot, a number of small areas of the same size and shape are studied in detail. These are called *sampling units*. The sum of these sampling units is called the *sample* of the plot. The total area included in the sample, expressed as a percentage of the area of the plot, is called *sampling percentage*.

Sampling error is given by $s/\sqrt{n}$ which is based upon an infinite population.

FIELD DATA AND THEIR INTERPRETATION

The general aspect of the typically semi-arid sagebrush-grass type (5, 12), dominated by the ever-present sagebrush, is one of apparent but not real uniformity in density and composition.

Yield data of arrowleaf balsamroot and tapertip hawksbeard, the two most important weed species of the sagebrush-grass type, indicate a high degree of variability. The variability of herbage yields of arrowleaf balsamroot (Table 1) is greater than twice that ordinarily encountered in cultivated crops and the variability of tapertip hawksbeard is two-thirds greater than that of balsamroot.

TABLE 1.—*Average air-dry herbage yields and variability of arrowleaf balsamroot and tapertip hawksbeard on 640 5 by 5 foot plots.*

Species	Average yield per plot, grams	Standard deviation per plot, grams	Coefficient of variability, %
Arrowleaf balsamroot	72.7	46.3	64
Tapertip hawksbeard	7.4	7.6	103

Frequency distributions (Fig. 1) of the herbage yields for both species are distinctly non-normal, that of hawksbeard approaching a Poisson distribution in character. Implications of this serious skewness and the effect of different plot sizes and conformations will be discussed later in this paper.

SAMPLING UNIT SIZE AND STRUCTURE AS AFFECTING VARIABILITY

Sampling unit size and structure have been found to play an important part in determining the accuracy of sampling (1, 2, 11). Variability may be expected to decrease with increased sampling unit size, but not in accordance with the expression $s/\sqrt{n}$ which is based on the premise that increase in (n) will be at random from the entire area. This, however, is not obtained by an increase in sampling unit size. Since, in actual practice, variability is reduced less by increasing sampling unit size than by equivalent random replication,

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Forms preferred when dealing with sampling from a finite population are $\sqrt{\frac{s^2}{n}-\frac{s^2}{N}}$ and $\sqrt{\frac{N-n}{N}\cdot\frac{s^2}{n}}$, where N is the number of possible sampling units in the area being sampled. When N is exceedingly large and the sampling percentage low, as is the case in most range experiments, sampling errors calculated from $s/\sqrt{n}$ will produce almost identical results with the preferred form and may be used for approximation. Sampling error is usually expressed as a percentage of the mean.

A precise expression for use in determining the number of sampling units needed for an allowable degree of accuracy is $n=\frac{s^2 N}{(s_{\bar{x}})^2(N-1)-s^2}$ where $(s_{\bar{x}})$ is the standard error of the mean that it is desired to secure. But, since no two areas are absolutely identical, for all practical purposes the commonly used formula $n=\frac{s^2}{(s_{\bar{x}})^2}$ will suffice. This latter formula was used in the following analyses.

smaller sampling units are usually more efficient. To provide data for studying the effect of sampling unit size and structure upon variability of the two native range species, yields for each sampling unit 5 by 5, 10 by 10, 20 by 20, 5 by 10, 5 by 20, 5 by 40, 10 by 20, and 10 by 40 feet in size were read from the balsamroot and hawksbeard herbage productivity charts.[5] Variability of yields for each individual plot size was calculated and expressed as variance (s^2). Mean squares,

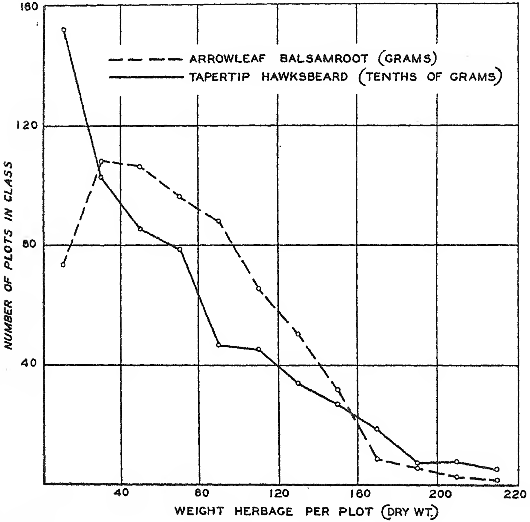

FIG. 1.—Distribution curves of herbage production by arrowleaf balsamroot and tapertip hawksbeard. Plots 25 square feet in area.

in variance, for the different-sized plots were expressed in terms of the 25-square-foot units to make them directly comparable. Efficiency is expressed as invariance, (7, p. 188), the smallest unit, 25 square feet, being considered as contributing 1 unit of information.

For evaluating the effect of size, comparisons were made between units of the same shape in order that any difference in efficiency would be attributable to size alone.

When expressed as invariance (Table 2), the greater efficiency of

[5]Copies of these tabular charts available upon request at the Intermountain Forest and Range Experiment Station, Ogden, Utah.

the smaller units is clearly evident. Square units, 25 square feet in area, are over twice as efficient per unit of area as are units of 100 square feet and five times as efficient as those of 400 square feet. Almost identical ratios exist between rectangular units twice as long as wide and 50 and 200 square feet in area and for units 100 and 400 feet in area with length four times the width. For both balsamroot and hawksbeard, the trends were similar to those found in agronomic experiments.

TABLE 2.—*Relative amounts of information derived per unit of area with different sizes, shapes, and types of sampling units.*

Sampling unit size	Mean square variance*	Invariance†	Units of information per 25 sq. ft.
Balsamroot, Rectangular Compact Sampling Units			
5 feet by 5 feet	2,144.69	0.000466	1.00
10 feet by 10 feet	4,710.30	0.000212	0.45
20 feet by 20 feet	10,723.46	0.000093	0.20
5 feet by 10 feet	2,983.78	0.000335	0.72
5 feet by 20 feet	3,934.24	0.000254	0.55
5 feet by 40 feet	4,561.03	0.000219	0.47
10 feet by 20 feet	6,444.36	0.000155	0.33
10 feet by 40 feet	7,347.15	0.000136	0.29
Hawksbeard, Rectangular Compact Sampling Units			
5 feet by 5 feet	58.10	0.017212	1.00
10 feet by 10 feet	146.35	0.006833	0.40
20 feet by 20 feet	278.63	0.003589	0.21
5 feet by 10 feet	95.09	0.010516	0.61
5 feet by 20 feet	114.71	0.008718	0.51
5 feet by 40 feet	152.98	0.006537	0.38
10 feet by 20 feet	194.21	0.005149	0.30
10 feet by 40 feet	265.30	0.003769	0.22
Balsamroot, Line-plot Sampling Units			
100 square feet in area			
4 subunits spaced 5 feet apart	2,904.21	0.000344	0.74
4 subunits spaced 15 feet apart	2,002.15	0.000499	1.07
4 subunits spaced 35 feet apart	2,013.67	0.000497	1.07
400 square feet in area			
4 subunits spaced 10 feet apart	3,533.13	0.000283	0.61
4 subunits spaced 30 feet apart	3,642.24	0.000275	0.59
Hawksbeard, Line-plot Sampling Units			
100 square feet in area			
4 subunits spaced 5 feet apart	85.78	0.011658	0.68
4 subunits spaced 15 feet apart	69.75	0.014337	0.83
4 subunits spaced 35 feet apart	65.29	0.015316	0.89
400 square feet in area			
4 subunits spaced 10 feet apart	171.54	0.005830	0.34
4 subunits spaced 30 feet apart	140.77	0.007104	0.41

*Mean square on the basis of 25 square foot units.
†Invariance (1/2144.69 = .000466) is the reciprocal of variance.

Increased sampling unit size, it can be seen by comparison of the frequency distributions for the 25- and 100-square-foot compact units (Figs. 1, 2, and 3), is markedly effective in reducing skewness. It may be advisable, in some cases, to utilize this principle, even though it

has been shown by several investigators that the "z" test is valid with rather skewed distributions, because some degree of uncertainty may accompany the interpretation of data from a distribution as skew as that of tapertip hawksbeard. Where species distributions are characteristically Poisson and experimental treatments have produced marked effects, the relation between the mean and variance for different treatments may invalidate the use of analysis of variance without suitable transformations of the data (3); but in dealing with

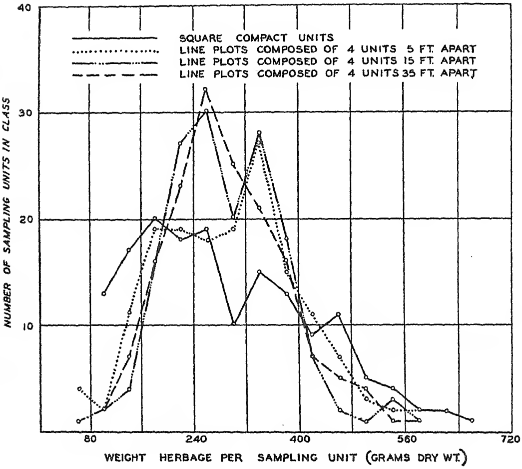

FIG. 2.—Distribution curves of balsamroot herbage production showing influence of type of sampling unit, 100 square feet in area, upon efficiency of sampling.

such distributions, increased sampling unit size has been found to render valuable assistance by decreasing the skewness of badly skewed distributions (6, 11).

Shape of sampling unit as a factor affecting variability was studied by comparing the efficiency of sampling units of the same area but having different dimensions.

In general, with both species, the efficiency of plots in which the length exceeds the width is slightly greater than that for square plots of the same area. Increases in efficiency through the use of long narrow units appears to be slightly more for balsamroot than hawksbeard, there being but little difference in the efficiency of 20 by 20 and 10 by 40 foot units for hawksbeard.

For both species, with 200-square-foot units, increases of length increased the information contributed, units 5 by 40 feet contributing 0.14 and 0.08 unit of information more, respectively, for balsamroot and hawksbeard than the 10 by 20 foot units. Since these limited data tend to follow the same trend found in agronomic experiments and in the studies of Hasel, it may be concluded that long narrow plots tend to be more efficient, though the increases in efficiency may be slight.

LINE-PLOT SAMPLING UNITS

The line-plot, a complex type unit suggested by Wishart (16) and used by Hasel (10), was tested because it may have some peculiarities that adapt it to use in sampling native range vegetation. Wishart (16) states, "The principle being conceded that a number of independently located sampling units are needed to give an estimate of error of sampling, modifications are possible in detail. For example, the sampling unit may be compounded of a number of systematically placed units. This not only saves labor, but is often a definite advantage." Few tests of the complex unit are available with which to judge the soundness of Wishart's assumptions.

Five different types of line-plot sampling units were tested using the uniformity charts. Line-plots 100 square feet in aggregate area composed of four 25-square-foot subunits spaced 5, 15, and 35 feet apart and line-plots 400 square feet in area using four square 100-square-foot units spaced 10 and 30 feet apart were tested. With each type of line-plot, each individual 25-square-foot plot was used but once. Variability in herbage yields are summarized in Table 2.

The 100-square-foot line-plot showed little loss of efficiency as compared with the 25-square-foot unit. With both balsamroot and hawksbeard, efficiency of the line-plot increases with the distance between the subunits, information furnished being about one-third greater when subunits are moved from 5 to 35 feet apart. This may indicate that the more nearly the subunits of a single sampling unit are spaced across the entire area or block being sampled, the more efficient the sampling unit will be. However, the increases from spacing the subunits of the line-plot will be slight when the distance between subunits becomes so great that correlation between adjacent subunits is negligible.

Line-plots 400 square feet in area are but about one-half as efficient as the 100-square-foot line-plots, but this is to be expected since they are compounded from 100-square-foot subunits which were only one-half as efficient as the 25-square-foot subunits (Table 2). With both species line-plots are about twice as efficient as the square sampling units and appreciably more efficient than rectangular sampling units of the same size.

With both balsamroot and hawksbeard, 100-square-foot line-plots decrease the skewness markedly more than 100-square-foot compact units (Fig. 3). As with efficiency and variability, the reduction in skewness becomes greater as the distance between subunits is increased.

Line-plot sampling units, approaching closely the existent method of sampling native range vegetation, would seem to be particularly

adaptable to use in the field. Random selection of the line-plot unit would be much less difficult than that of the compact type unit of similar area. However, the same factors affecting the efficiency of the compact type sampling units will alter the desirability of the type subunit compounded into line-plots, and full cognizance should be given these factors in selecting subunits for use with line-plots.

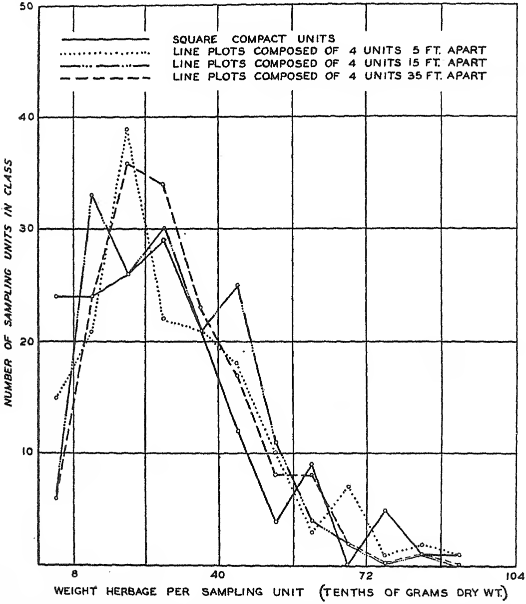

FIG. 3.—Distribution curves of tapertip hawksweed herbage production showing the influence of type of sampling unit, 100 square feet in area, upon efficiency of sampling.

METHODS OF SAMPLING

Sampling aims at two objectives, representative estimates of the mean yield and of the population variance. The certainty with which sampling meets its objectives is dependent upon the method of sampling unit placement. In range studies three general types of placement have been used, *viz.*, typical, systematic, and random, each having it exponents. Each method also has some disadvantages

either in failing to fulfill the objectives of sampling or in difficulty of application in the field.

With typical sampling, several units selected as typical of the whole area are studied intensively, the average being thought to provide information pertinent to the entire area. Since individual units are selected in conformity with the observer's idea of average, it is unlikely that the estimate of error is valid. It has been found that such estimates of the mean yield are apt to portray, in part, the picture in the mind of the observer rather than its true condition. Typical sampling, therefore, provides a poor estimate of population variance and a biased estimate of the mean. Even when the entire population can be inspected, selection based on the judgment of the observer has been found to give samples which are usually biased (4, 18).

Systematic sampling was introduced in an endeavor to eliminate the personal factor inherent in typical sampling. Sampling units spaced at regular intervals along a line or in a gridiron arrangement eliminated the effect of personal bias. Ease of application and the apparent greater reliability of means hastened the acceptance and wide usage of systematic sampling. A fully representative sample, however, only obtained when each individual unit in the area being sampled has an equal chance of being chosen, is not secured by systematic sampling; the estimate of the mean may be representative but biased estimates of variability are usually obtained (2, 10).

A representative sample is secured only when sampling is at random. However, when highly variable material is dealt with, averages calculated from samples secured wholly at random may vary widely. This factor, together with such practical considerations as difficulty in field location and the difficulty of mapping types, has given rise to the wish to obtain some of the benefits of systematic methods. Considerable attention has been devoted to the problem of random sampling in an endeavor to improve accuracy of the means while still retaining a sufficient element of randomness to make the sample representative.

It is interesting to note that the greater reliability of means secured by systematic sampling, to be expected, may not always be attained. From data presented by Hasel (10) means of 56 random within-block samples had a variance of 184 as compared to a variance of 207 for 16 systematic cruises. For random line-plot samples, the population variance between cruises was 222. This differs from the variance of 207 by no more than would result from chance alone, indicating that means secured by random sampling were equal in precision to those secured by systematic sampling.

SUBDIVISION IN RANDOM SAMPLING

Several modifications are possible in the details of random sampling that may promote accuracy. Of these, subdivision offers much promise. Subdivision, the division of the area or population to be sampled into a number of groups so chosen that the species being studied varies little within each group and obtaining at random at least two sampling units from each group, has been found with heterogenous populations to provide more reliable means and smaller

sampling errors. For example, where 40 sampling units are to be used, the area might be subdivided into four blocks and from each block 10 sampling units drawn at random. In analysis, variance would be divided into that between and that within blocks, the latter being used for the calculation of sampling error or population variance. This procedure would result in a substantial reduction in sampling error by eliminating variability between blocks. The object of subdivision is to have the area within groups as uniform as possible, leaving most of the variation to occur between the groups.

The relative merits of subdivision and complete randomization were tested by using the balsamroot and hawksbeard productivity charts, on each of which were located 16 line-plots, 100 square feet in aggregate area with subunits 15 feet apart. For complete randomization, the population variance, to which the values from repeated random samplings would tend, was used. For subdivision, four sampling units were drawn from each of the four blocks, 50 by 80 feet in size, into which the area was arbitrarily divided. With a sampling percentage of 10, and complete randomization, sampling errors of 7.7 and 14.1% are expected, respectively, for balsamroot and hawksbeard.

The mean square variance between samples with subdivided random sampling is substantially less than that expected by strictly random sampling (Table 3). Through subdivision, the information secured was increased 0.29 and 0.22 unit, respectively, for balsamroot and hawksbeard.

TABLE 3.—*Analysis of variance of subdivided random sampling.*

Source of variation	Degrees of freedom	Sum of squares	Mean square
Arrowleaf Balsamroot, Random Sampling, Population Variance			
Between samples	—	—	8,008.58
Arrowleaf Balsamroot, Subdivided Random Sampling			
Between samples	19	139,438.16	7,338.85
Between blocks within samples	60	648,157.38	10,802.62
Between units within blocks (error)	240	1,489,906.82	6,207.95
Total	319	2,277,502.36	
Tapertip Hawksbeard, Random Sampling, Population Variance			
Between samples	—	—	278.89
Tapertip Hawksbeard, Subdivided Random Sampling			
Between samples	19	2,488.58	130.98
Between blocks within samples	60	26,584.84	443.08
Between units within blocks (error)	240	54,797.25	228.32
Total	319	83,870.67	

These increases in accuracy, even on the limited area used, can be secured at the cost of only slight additional planning. On more extensive areas even greater benefits would likely accrue from subdivision and it appears that this method warrants actual field trial.

PRACTICAL CONSIDERATIONS

If the information per unit area were the only criterion of sampling unit efficiency, then the smaller the unit the more efficient it would be, and long narrow compact units would be slightly more efficient than square or round units of the same size. Line-plot sampling units would be particularly promising in efficiency, reduction of skewness, and apparent adaptability for field use. With a constant sampling percentage, however, other practical factors must be considered.

Chief of the practical considerations are the time factors affecting the number of units it is possible to use and the cost of sampling. Some of these factors are:

1. Time spent in walking between sampling units and in locating the permanent markers increases with their distance apart, but not in proportion to increases of unit area. Thus, more time will be required per unit with large than with small units.
2. Time spent in marking out the sampling unit boundary varies nearly directly with the length of the boundary line. With square or rectangular plots of such size that a boundary frame cannot be conveniently used, additional time will be required to lay out the unit and check the corners. In comparison, circular plots require the least time on initial location since they call for the permanent location of only one point, the center.
3. Where measurement of vegetation on the sampling unit is by estimate methods, the time required does not increase directly with the area of the unit except as the number of species may increase with size. Where shrubby species predominate, difficulty in observation is encountered through the use of large units. With clipping methods, time required will vary almost directly with the area.
4. Compilation requires only a slight increase in time per unit for larger units, owing to the slightly larger species list. The labor of analysis of the data from an area increases with the number of individual entries it is necessary to handle. Especially is this the case when a number of statistical analyses is contemplated.

In Table 4 are presented some estimates, based on considerable experience, showing the approximate relative amounts of time required per sampling unit for each of the above procedures as influenced by size of plot. For example, with the 25-square-foot unit, 8% of the total time is spent in walking between sampling units and locating unit markers. The 100-square-foot unit requires 20% more time to complete this operation than the 25-square-foot unit.

Practical considerations of time tend largely to overcome any advantages in statistical efficiency of smaller units. Where estimate methods are used, the relative units of information returned per unit of time are nearly identical for the 25-, 100-, and 400-square-foot units. Since time requirements are estimates, the slight superiority in information per unit of time on the larger units may well be ignored.

TABLE 4.—*Relative time requirements for performing various tasks in the collection and compilation of field data derived with sampling units of different sizes and the effect of time requirement on efficiency.*

Method	Time required in % of total time spent per unit	Effect of sampling unit size on time required, %		
		25 sq. ft.	100 sq. ft.	400 sq. ft.
Walking between units and locating markers:				
Estimate methods	8	100	120	145
Clip methods	2	100	120	145
Laying out boundary of unit:				
Estimate methods	2	100	180	300
Clip methods	1	100	180	300
Securing record on unit:				
Estimate methods	30	100	250	700
Clip methods	81	100	400	1,600
Compilation estimate methods	60	100	110	125
Clip methods	16	100	110	125
Average units of time required per sampling unit:				
Estimate methods	—	1.00	1.54	3.03
Clip methods	—	1.00	3.46	13.22
Units of information per sampling unit (balsamroot)*	—	1.00	1.80	3.20
Information per unit of time:				
Estimate methods	—	1.00	1.17	1.06
Clip methods	—	1.00	0.52	0.24

*From Table 2.

When clipping methods are used, time required per sampling unit varies almost directly with size (Table 4). With clipping methods, therefore, the smaller the sampling unit the greater the efficiency.

Besides the time requirements, points relative to the accuracy of observation must be considered. First, the smaller the unit the greater the error in the study of the less prevalent species. Since secondary species occur less and less abundantly on smaller sampling plots, these species will more often fail to be present in sufficient volume to have a quantitative value assigned them, even where they occur on the unit. Second, when estimate methods are used, it is likely that records on small plots will be taken more carefully than on larger ones where scarce plants or species may be overlooked. With large units there is a tendency for the observer to be disproportionately influenced by the last segment of the unit he views. As Stapledon (15) has stated in favoring the small unit, "it makes you look at it as a whole—you concentrate attention upon it, and thus the greater your number of replications by that much deeper and more intensive your contemplations." With shrubby vegetation smaller size promotes accuracy of observation even more than on open grassland or weed types.

The line-plot sampling unit, when randomized, is particularly easy to locate and use, and is comparable to systematic plot arrangements in this respect. However, all factors affecting time requirements and accuracy of observation apply to the subunits of the line-plot and should be weighed fully in its selection.

Since in selecting sampling unit size, the efficiency from the standpoint of information secured for each unit of area must be considered as well as the reduction of skewness and such practical factors as rapidity, ease, and accuracy of observation, the data presented herein do not completely solve the problem of optimum size and shape.

So many factors are involved which do not permit linear expression that the use of such a formula as Smith (13) found appropriate for determining optimum size of sampling unit is difficult. Experienced judgment, together with acquaintance of the extent and importance of factors that influence optimum size and structure, may be as effective as empirical formulae. Here the problem is to strike a balance between the amount of work, accuracy of observation, and statistical efficiency, for it is often less expensive to collect data from a few large sampling units than from several widely separated small units.

Even though subdivision in random sampling in this study was not tested in the field, it has been shown in other investigations (2, 10, 11, 13) to be a profitable method of increasing sampling accuracy, and often in promoting ease of administration. For this reason, it seems worthy of a trial in sampling native vegetation.

On the basis of this study and consideration of practical factors involved, it is recommended that for sampling native sagebrush-grass range line-plot sampling units, composed of subunits 50 to 100 square feet in area, located at random within subdivisions of the area, be considered for use. Since each study area presents problems of sampling differing somewhat from those elsewhere encountered, it is obvious that results from this study should be directly applied to another area only after a preliminary trial.

SUMMARY

Some problems involved in sampling of native sagebrush-grass range areas were studied at the U. S. Sheep Experiment Station, Dubois, Idaho. On a block of native range, 3/8 acre in area, the herbage of arrowleaf balsamroot (*Balsamorhiza sagittata*) and tapertip hawksbeard (*Crepis acuminata*) was harvested. The area was subdivided into 640 5 by 5 foot plots and the weight of air-dry herbage of each species recorded for each plot. This information was used in testing the efficiency of various sampling unit sizes and shapes and in exploring the influence of subdivision of sampling upon accuracy of the sample.

From a statistical standpoint the smaller the sampling unit the more efficient it is per unit of area. Long narrow sampling units are generally somewhat more efficient than square ones, but the increase may be slight. The line-plot sampling unit, with subunits spaced at systematic intervals along a line, is the most efficient unit studied. However, in selecting a sampling unit for field use, derived from such a

trial as herein conducted, an effective balance must be struck between statistical efficiency and such practical factors as the amount of work and accuracy of observation.

Representativeness, only achieved when the essential element of random selection is included in the sampling procedure, may be conveniently secured in sampling native ranges by use of the line-plot sampling unit.

Subdivision, when tested on uniformity trial data of this study, appears to be a profitable method of improving the accuracy of random sampling on heterogeneous areas.

Subdivided random sampling, using line-plot sampling units, whose subunits are circular plots approximately 50 square feet in area, is recommended for trial in sampling range areas similar to that on which this study was conducted.

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THE VERTICAL DISTRIBUTION OF TOTAL AND DILUTE ACID-SOLUBLE PHOSPHORUS IN TWELVE IOWA SOIL PROFILES[1]

R. W. Pearson, Robert Spry, and W. H. Pierre[2]

VERY few detailed studies of the vertical distribution of either total or dilute acid-soluble phosphorus in soils have been reported, although innumerable analyses of surface layers have been made. Since plants undoubtedly absorb considerable quantities of nutrients from the lower soil horizons, knowledge of the total and easily soluble phosphorus content at different depths in the profile should be useful in estimating the ability of a soil to supply phosphorus to plants. Such investigations, when made with carefully selected and sampled profiles, would also provide valuable data for soil genesis and classification studies.

An examination of the reported determinations of total phosphorus at different depths in soils reveals wide variations in the vertical distribution of this element. Odynsky (5)[3] found a regular decrease in total phosphorus with depth in one of five Alberta soils. In the four other soils studied a minimum occurred in the intermediate layers. Wheeting's (11) results with five Michigan soils show wide differences in the relative amounts of phosphorus found at four depths. In two of the soils the highest percentage was found in the A horizon, in two others in the B horizon, and in one soil the highest percentage was found in the C horizon. Similarly, Stephenson and Chapman (7) found no consistent relation between the phosphorus content of various layers in 11 California soils included in their study. Walker and Brown (3) analyzed samples taken at 0 to 6⅔ inches and 20 to 40 inches. Their results show that larger amounts of phosphorus are present in the surface layer than in the 20- to 40-inch zone.

The fact that the available data show such wide variations in the vertical distribution of total phosphorus may be due, in part, to inadequate sampling; relatively few samples were taken from each profile in most cases, and in a number of studies no samples were taken from the C horizon.

The previously reported investigations of easily soluble phosphorus content at different depths in soils indicate that the amounts present in the C horizon may often be higher than in the upper part of the profile. Alway, McDole, and Rost (1) reported that citric acid-soluble phosphorus increased rapidly to a depth of 6 feet in several soils developed from loess. Below this point constant amounts were found. Phosphorus dissolved by 0.002 N H_2SO_4 was found by Romine and Metzger (6) to be lower in the B than in the A horizons of six out of eight prairie soils studied, and higher in the C than in either the A or B horizons in five of the eight soils. Stephenson and Chapman (7)

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[3]Figures in parenthesis refer to "Literature Cited", p. 695.

found an increase in soluble phosphorus with depth in 4 of the 11 California soils included in their investigation. Since in this study the deepest sampling was from 24 to 36 inches, the C horizon was probably not included. Lohse and Runke (4) reported an increase of soluble phosphorus with depth below the A_2 horizons of virgin Podsolic and Brown Forest soils in Ontario. Odynsky (5) found that phosphorus dissolved by 0.002 N H_2SO_4 increased with depth throughout the profiles of three dark-colored unleached Alberta soils. In two gray severely leached soils a minimum occurred in the B_1 horizon below which the amounts increased to the bottom of the profile. A Marshall silt loam was found by Truog (8) to contain only a trace of dilute acid-soluble phosphorus at a depth of 2 feet, while below this depth the amounts increased rapidly to a maximum in the C horizon.

EXPERIMENTAL

DESCRIPTIONS OF SOILS STUDIED

The samples used in this study were obtained from 12 soil profiles representing 11 soil series which occur in Iowa.[4] These profiles represent three of the great soil groups: The Planosol, Prairie, and Gray-Brown Podsolic soils. The soil types, great soil groups, number of layers analyzed, and profile number are given in Table 1.

TABLE 1.—*Soils used in study.*

Soil type	Profile No.	Great soil group	No. of layers analyzed
Carrington silt loam	P-52	Prairie	11
Lucas silt loam	P-3	Prairie	10
Marshall silt loam	P-51	Prairie	12
Tama silt loam	P-27	Prairie	9
Tama silt loam (virgin)	P-100	Prairie	12
Shelby silt loam	P-5	Prairie	11
Waukesha silt loam	P-26	Prairie	10
Grundy silt loam	P-1	Planosol	10
Edina silt loam	P-2	Planosol	13
Muscatine silt loam	P-30	Planosol	8
Fayette silt loam (virgin)	P-32	Gray-Brown Podsolic	13
Weller silt loam (virgin)	P-4	Gray-Brown Podsolic	11

The Shelby and Carrington were developed from glacial till and the Waukesha from alluvial material. All the other soils listed were formed from loess. Only three of these soils, the Fayette, Weller, and Tama (P-100), are represented by virgin profiles.

METHOD OF SAMPLING

Pits were dug to a depth of about 5 feet and samples taken from the pit walls. The surface layers from profiles of soils recently cultivated were taken to a depth of 6 inches. All other samples were taken in layers that were horizons or subdivisions of horizons not thicker than 4 inches. From 15 to 20 samples were taken from each profile, but not all were analyzed, the usual procedure being to analyze alternate layers in the lower horizons.

[4]The authors are indebted to Dr. Roy W. Simonson for collecting the profile samples used in this study.

ANALYTICAL METHODS

For determination of total phosphorus 0.2 gram of finely ground soil was fused with 3 grams of Na_2CO_3. The melt was extracted with hot water, diluted to 500 cc, and phosphorus determined colorimetrically on aliquots of the filtered solution using Truog and Meyer's (10) modification of the Deniges method.

Dilute acid-soluble phosphorus was determined using the method proposed by Truog (9).

The Coleman electrometer was used for pH determinations. One part of soil and 2½ parts of water were shaken for 30 minutes prior to the determination.

RESULTS

The amounts of total and dilute acid-soluble phosphorus and the pH of the layers analyzed are given in Table 2, and the distribution of total and dilute acid-soluble phosphorus within the profiles are presented graphically in Figs. 1 and 2.

TOTAL PHOSPHORUS

An examination of Fig. 1 shows that the amounts of total phosphorus in all the profiles studied decreases with depth from the surface layers to a minimum at from 10 to 30 inches. Below this zone there is in most of the profiles a marked increase with increasing

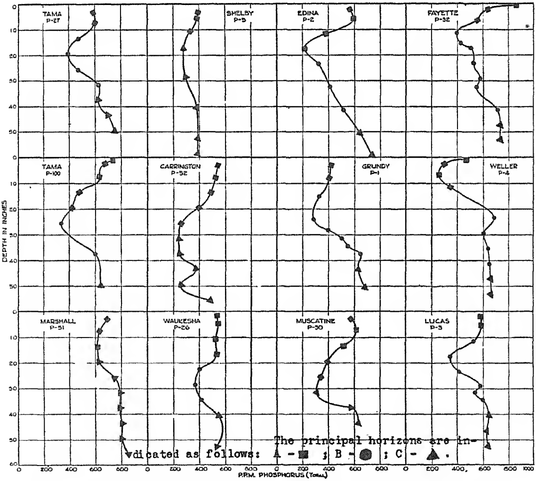

FIG. 1.—Vertical distribution of total phosphorus in 12 Iowa soil profiles.

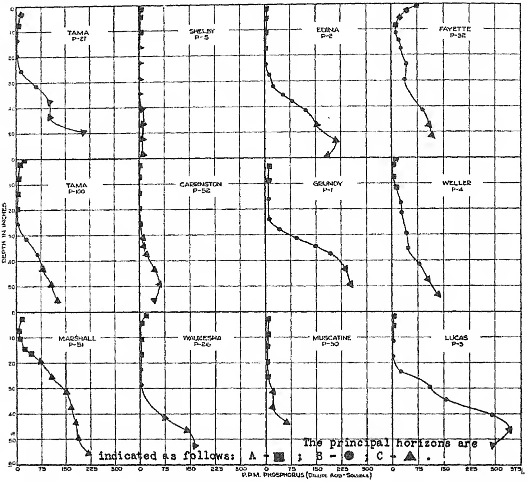

FIG. 2.—Vertical distribution of dilute acid-soluble phosphorus in 12 Iowa soil profiles.

depth to a maximum in the C horizon. There are large differences, however, both within soil groups and between groups, in the rates of change of total phosphorus with depth, in the total amounts present, and in the location within the profiles of horizons in which minimum amounts occur.

Within the Prairie soil group, the two Tama profiles and the Lucas, which contains from 585 to over 700 p.p.m. of phosphorus in the A horizon, show a rapid decrease of total phosphorus with depth to a minimum of about 350 p.p.m. in the upper B horizon. Below this zone the amounts increase, sharply at first and then more slowly, to a maximum of 650 to 750 p.p.m. in the C horizon. In the Carrington and Shelby profiles, on the other hand, the initial decrease with depth is gradual. The quantities found throughout the profiles are much smaller than in the other soils of this group and the amounts present in the C horizon are not quite as high as in the surface layer. The Marshall profile shows tendencies similar to the Shelby in distribution of total phosphorus, although the quantities present in the Marshall are much greater, amounting to 800 p.p.m. in the C horizon as compared to less than 400 p.p.m. in the Shelby.

Marked differences were found between soils of the Planosol group in distribution of phosphorus, although the total amounts present

TABLE 2.—*Total and dilute acid-soluble phosphorus amd pH at various depths in 12 Iowa soil profiles.*

Horizon	Depth, inches	Depth of sample, inches	Total P, p.p.m.	Dilute acid-sol. P, p.p.m.	% total P soluble in dil. acid	pH
			Tama Silt Loam (P-27)			
A_1	0–6	0–6	585	11.5	1.9	5.1
A_{11}	6–13	6–9	596	4.4	0.7	5.3
B_1	13–18	12–15	470	3.7	0.7	5.5
B_2	18–24	18–21	386	3.1	0.8	5.4
B_3	24–37	24–27	465	14.5	3.1	5.2
		30–33	622	62.0	9.9	5.3
C_1	37–48	36–39	620	95.0	15.3	5.5
		42–45	699	98.0	14.0	5.8
C	48+	48–51	750	207.0	27.6	5.8
			Tama Silt Loam (P-100)			
A_1	0–1½	0–1½	738	23.2	3.1	7.0
A_{11}	1½–12	1½–3	676	13.9	2.0	6.2
		6–9	631	7.7	1.2	5.7
A_3	12–21	12–15	465	6.3	1.3	5.6
		18–21	408	5.2	1.2	5.4
B_2	21–30	24–27	332	7.1	2.1	5.4
B_3	30–39	30–33		31.9		4.7
		36–39	599	64.1	10.7	5.6
C_1	39–51	42–45		82.6		5.6
		48–51	641	108.0	16.8	5.5
C	51–72	54–57		126.0		5.5
		60–72	684	178.0	26.0	6.2

are comparable. In the Edina, phosphorus decreases rapidly with depth from 595 p.p.m. in the 4- to 7-inch layer to a minimum of only 217 p.p.m. in the lower A horizon, while in the Grundy and Muscatine the decrease is more gradual and the lowest amounts occur at 22 to 26 inches and 30 to 33 inches, respectively. In all three soils maximum amounts of phosphorus occur in the lower part of the C horizon.

The distribution of total phosphorus in the two Gray-Brown Podsolic soils, Fayette and Weller, is quite similar, but the amounts

TABLE 2.—*Continued.*

Horizon	Depth, inches	Depth of sample, inches	Total P, p.p.m.	Dilute acid-sol. P, p.p.m.	% total P soluble in dil. acid	pH
		Marshall Silt Loam (P-51)				
A_1	0–6	0–6	698	17.4	2.4	5.6
A_{11} & A_3	6–18	6–9	634	7.8	1.2	5.6
		9–12		12.4		5.6
		12–15	618	25.3	4.0	5.8
		15–18		43.0		5.8
C_1	18–36	18–21	633	73.0	11.5	5.8
		24–27	759	107.0	14.1	6.2
		30–33	794	151.0	19.0	6.2
C	36–57	36–39	790	166.0	21.0	6.2
		42–45	806	180.0	22.3	6.3
		48–51	800	186.0	23.2	6.3
		54–57	855	217.0	25.3	6.2
		Lucas Silt Loam (P-3)				
A_1	0–7	0–4	583	5.5	0.9	5.2
A_{11}	7–12	4–7	583	4.4	0.7	5.1
B_1	12–16	10–13	524	3.4	0.6	5.0
B_{11}	16–20	16–19	341	3.1	0.9	5.1
B_2	20–29	22–25	416	24.0	5.7	5.4
		28–30	579	109.0	18.8	6.1
B_3	29–41	33–36	599	155.0	25.8	6.4
		39–42	645	291.0	45.1	6.5
C	41–56	45–48	622	340.0	54.6	6.5
		51–54	634	293.0	46.2	6.6

present in the surface layers are widely different. In the Fayette a rapid decrease with depth from 860 p.p.m. in the A horizon to a minimum of 396 p.p.m. at 10 to 13 inches was found. In the Weller the phosphorus content dropped from 468 p.p.m. in the surface to 258 p.p.m. in the 6- to 8-inch layer. Below the zone of minimum phosphorus content there is a general, though irregular, increase to about 700 p.p.m. at the bottom of the profile.

TABLE 2.—*Continued.*

Horizon	Depth, inches	Depth of sample, inches	Total P, p.p.m.	Dilute acid-sol. P, p.p.m.	% total P soluble in dil. acid	pH
		Shelby Silt Loam (P-5)				
A_1	0–9	0–3	396	4.7	1.1	5.1
		3–6	385	4.7	1.2	5.1
A_3	9–15	9–12	338	3.3	0.9	4.8
C_1	15–24	15–18	286	Trace		4.9
		21–24		Trace		4.7
C_2	24–36	27–30	298	Trace		5.0
		33–36		Trace		5.0
C_{21}	36–42	39–42	385	8.4	2.1	5.1
C_{22}	42–60	45–48		9.8		5.7
		51–54	390	10.3	2.6	5.5
		57–60	388	10.7	2.7	5.4
		Carrington Silt Loam (P-52)				
A_1	0–6	0–6	543	5.3	0.9	5.2
A_{11}	6–16	6–9	526	3.0	0.5	5.2
		12–15	486	2.5	0.5	5.2
A_3	16–26	18–21	397	2.2	0.5	5.3
		24–27	261	3.8	1.4	5.2
C_1	26–40	30–33	244	9.8	4.0	5.5
		33–36		12.5		5.6
		36–39	251	22.0	8.7	5.6
C	40–57	42–45	371	46.0	12.4	5.7
		48–51	259	60.0	23.1	6.0
		54–57	483	44.0	9.1	6.1

A comparison of soil groups on the basis of total phosphorus distribution is difficult because of the wide differences within the Prairie group, particularly between the soils formed from till and those developed on loess. In general, the Planosol soils studied tend to resemble those of the Prairie group and both groups differ distinctly from the Gray-Brown Podsols.

TABLE 2.—*Continued.*

Horizon	Depth, inches	Depth of sample, inches	Total P, p.p.m.	Dilute acid-sol. P, p.p.m.	% total P soluble in dil. acid	pH
			Waukesha Silt Loam (P-26)			
A_1	0–6	0–3	537	19.5	3.6	4.8
		3–6	545	5.3	0.9	4.8
A_{11}	6–12	9–12	526	4.0	0.7	5.0
A_3	12–21	15–18	533	3.8	0.7	5.0
B_2	21–39	21–24	402	2.5	0.6	5.4
		27–30	373	3.9	1.0	5.2
		33–36	416			5.0
C	39–54	39–42	555	73.8	13.2	5.2
		45–48		140.0		4.9
		51–54	536	162.0	30.2	5.2
			Muscatine Silt Loam (P-30)			
A_1	0–6	0–6	575	8.5	1.4	5.0
A_2	6–20	6–9	618	6.9	1.1	5.2
		12–15	518	6.4	1.0	5.4
		18–21	395	5.8	1.4	5.4
A_3	20–25	24–27	349	6.4	1.8	5.7
C_1	25–32	30–33	307	21.0	6.8	6.5
C	32–48	36–39	576	20.0	3.4	7.0
		42–45	632	62.0	9.8	7.0

DILUTE ACID-SOLUBLE PHOSPHORUS

Fig. 2 shows the vertical distribution of phosphorus soluble in 0.002 N H_2SO_4 in the 12 profiles included in this study. In most of the soils soluble phosphorus decreased slightly with depth to the lower A or upper B horizons and then increased rapidly to the bottom of the profile.

Within the Prairie group the Shelby and Carrington, which were developed from glacial till, contain very low amounts of dilute acid-soluble phosphorus throughout the profile, although there is a slight increase in the lower layers. No layer in either profile to a depth of 3 feet contained more than 12.5 p.p.m. of easily soluble phosphorus, while the highest amount found at any depth was 60 p.p.m. In the Prairie soils formed from loess the increase below the zone of mini-

TABLE 2—*Continued.*

Horizon	Depth, inches	Depth of sample, inches	Total P, p.p.m.	Dilute acid-sol. P, p.p.m.	% total P soluble in dil. acid	pH
			Edina Silt Loam (P-2)			
A_1	0–4	0–4	570	6.7	1.1	5.0
A_2	4–11	4–7	595	6.2	1.0	5.1
		10–13	381	5.0	1.3	5.1
A_{21} & A_{22}	11–19	16–19	217	2.8	1.2	5.5
B_2	23–34	22–25	322	3.0	0.9	5.3
		28–31		13.5		5.5
		31–34	409	24.4	5.9	5.6
B_3	34–46	34–37		53.0		5.5
		37–40		82.0		5.8
		40–43	511	121.0	23.6	5.8
C_1	46–56	46–49		153.0		6.1
		49–52	643			
		52–55		206.0		6.2
C	56–65	58–61	738	186.0	25.2	6.2
			Grundy Silt Loam (P-1)			
A_1	0–6	0–6	418	11.1	2.6	5.3
A_3	6–14	6–10	405	8.9	2.2	5.6
B_1	14–18	14–18	327	9.0	2.7	5.9
B_2	18–26	22–26	288	10.0	3.4	6.3
B_{21}	26–30	26–30	397	41.5	10.4	6.1
B_3	30–38	30–33	507	92.5	18.2	6.9
		33–36	551	148.0	26.8	6.7
		36–39	647	192.0	29.6	6.9
C_1	38–48	42–45	630	235.0	37.3	7.0
C	48–56	48–51	685	249.0	36.3	7.0

mum phosphorus content is very rapid and larger quantities are present, ranging, with one exception, from 162 to 340 p.p.m. in the C horizons.

The distribution of easily soluble phosphorus in the Edina and Grundy profiles is quite similar. In both soils the amounts decrease

TABLE 2.—*Concluded.*

Horizon	Depth, inches	Depth of sample, inches	Total P, p.p.m.	Dilute acid-sol. P, p.p.m.	% total P soluble in dil. acid	pH
		Fayette Silt Loam (P-32)				
A_1	0–1½	0–1½	860	74	8.6	6.4
A_2	1½–4	1½–4	639	42	6.5	5.0
A_{21}	4–10	4–7	552	23	4.1	4.5
		7–10		14		4.6
B_1	10–16	10–13	396	12	3.0	4.7
		13–16	421	20	4.7	4.9
B_2	16–19	16–19	507	26	5.1	4.8
B_{21}	19–31	22–25	528	41	7.7	4.8
		28–31	579	38	6.5	4.8
B_3	31–46	31–34	550			5.1
		40–43	718	92	12.8	5.1
C	46–54	46–49	738	109	14.7	5.1
		49–54	732	118	16.1	5.2
		Weller Silt Loam (P-4)				
A_1	0–1½	0–1½	468	13.8	2.9	5.3
A_2	1½–6	1½–4	293	4.5	1.5	5.2
A_{21}	6–10	6–8	258	5.9	2.2	4.5
A_3	10–13	10–13	341	12.4	3.6	4.2
B_2	13–30	16–19		26.0		4.0
		22–25	687	29.0	4.2	3.8
		28–31	601	42.5	7.0	4.0
B_3	30–38	34–37	637	46.0	7.2	4.0
		40–43	649	80.5	12.4	4.1
C	38–58	46–49	661	106.0	16.0	4.5
		52–55	664	136.0	20.4	4.8

slightly with depth to the upper B horizon and then increase very rapidly through the lower layers of the profile to a maximum of over 200 p.p.m. Although the distribution in the upper part of the Muscatine profile is similar to that in corresponding zones in the Edina and

Grundy, the quantities present in the C horizon are much lower, amounting to only 62 p.p.m. It should be noted, however, that the C horizon in the Muscatine occurs at 32 to 48 inches, while in the Grundy and Edina it is found at 48 to 56 and 56 to 65 inches, respectively.

The distribution of dilute acid-soluble phosphorus in the Fayette and Weller profiles is very similar, although the amounts present in the surface of the Fayette are much greater than in the Weller. In both soils there is a pronounced decrease in the A horizon followed by a rather gradual increase to slightly over 100 p.p.m. in the C horizon.

As shown in Table 2, the percentage of total phosphorus soluble in dilute acid decreases slightly from the surface to the lower A or upper B horizon and then increases with depth. These data indicate that a larger percentage of the total phosphorus is soluble in dilute acid in the soils developed from loess than in those formed from till. It is interesting to note that more than 25% of the total phosphorus in the lower horizons of seven of the soils is soluble in dilute acids. In the C horizon of the Lucas this fraction amounted to 54%.

GENERAL DISCUSSION

Total phosphorus in all the profiles studied was found to decrease with depth, after a slight initial increase in several of the cultivated soils, to a minimum which generally occurred in the lower A or upper B horizons. Below this zone the amounts increased with depth to the C horizon, where in a number of cases the highest values were found. The general occurrence of a zone of minimum phosphorus content below the surface layers is possibly the result of absorption by the native vegetation over long periods of time. In this way the concentration of phosphorus in the surface could have been increased at the expense of the underlying layers. However, the surface layers do not contain large enough amounts to account for the phosphorus lost from the lower A and upper B horizons. Erosion may have caused considerable loss from the surface layers of some of the soils, but in others, such as the Grundy, which occur on very flat areas, this seems questionable. Other possible explanations would be variations in the original loess deposits or translocation of phosphorus within the profiles.

The differences between soils in content and vertical distribution of total phosphorus can be attributed to variations in both parent materials and the conditions under which the profiles developed. Thus the soils formed from loess contain larger amounts of phosphorus in the C horizon and generally more in the surface layers than those developed from glacial till, indicating a higher original phosphorus content in the loess than in the till. The dissimilarity between the Gray-Brown Podsolic soils and those of the Prairie and Planosol groups is due primarily to the fact that the former were developed under forest while the latter were formed under grass vegetation. The resulting difference in the location within the profiles of zones of maximum root development may be responsible for variations in phosphorus distribution.

In 9 of the 12 profiles studied the dilute acid-soluble phosphorus was found to increase greatly with depth, after an initial decrease to a minimum in the lower A or upper B horizons. A question immediately arises concerning the form in which this phosphorus could be present to account for its high solubility in the lower part of the profile. There is no consistent relation between the pH and easily soluble phosphorus content of the different horizons. For example, the C horizons of the Muscatine and Grundy soils both have pH values of about 7.0 and the maximum amount of dilute acid-soluble phosphorus in the former is only about one-fourth as high as in the latter. Likewise the C horizon of the Tama (P-27), which has a pH of 5.8, contained 207 p.p.m. of dilute acid-soluble phosphorus or about the same amount as the Grundy.

The work of Heck (2) indicates that calcium phosphates are rapidly dissolved by 0.002 N H_2SO_4, while the more difficultly soluble iron and aluminum phosphates continue to release phosphorus in a number of successive extractions. On the basis of these differences in rates of solution, re-extraction studies have been made on several samples in an attempt to determine the nature of the phosphorus compounds present in the lower horizons. Preliminary results show that large amounts of phosphorus are dissolved by re-extraction. According to Heck (2), this indicates that the large amounts of dilute acid-soluble phosphorus in the subsoils are due to the presence of iron and aluminum phosphates rather than calcium phosphates. It seems questionable, however, that large amounts of iron and aluminum phosphates would be present in the C horizon of soils like Grundy and Marshall that are neutral or only slightly acid in reaction.

Insufficient data are available from field experiments in the immediate vicinity from which the profiles were taken to justify an attempt to relate definitely the dilute acid-soluble phosphorus content of these profiles to crop response. However, it has been found generally true that the Shelby and Carrington soils, which contain the lowest amounts of dilute acid-soluble phosphorus throughout the profile, are among the most responsive to phosphate applications of the soils found in the state. Of course, other soil characteristics, such as the presence of a heavy B horizon, would influence to a considerable degree the use plants could make of available phosphorus present in the C horizon.

Although the data presented indicate that the lower part of the soil profile may play an important part in supplying phosphorus to growing plants, further investigation in the greenhouse and in the field will be necessary before this question can be definitely answered.

SUMMARY

Twelve soil profiles representing 11 soil series which occur in Iowa were selected for a study of the vertical distribution of total and dilute acid-soluble phosphorus. Seven of the soils studied belong to the Prairie, three to the Planosol, and two to the Gray-Brown Podsolic groups. The profiles were sampled in layers that were horizons or subdivisions of horizons not exceeding 3 inches, except the Grundy silt loam which was sampled in part at 4-inch intervals.

Two of the Prairie soils were developed from glacial till and one from alluvial material. The other nine soils were formed from loess.

In all the profiles studied total phosphorus was found to decrease with depth to a minimum between the lower A and upper C horizons. Below this zone, in 11 of the 12 soils, the amounts increased rapidly with depth to the bottom of the profile. In eight of the soils the concentration of phosphorus in the C horizon was more than double that in the lower A to upper B horizons.

The soils developed from till contained much smaller quantities of total phosphorus throughout the profile than those formed from loess. The former contained an average of about 300 p.p.m. of phosphorus as compared to 500 to 700 p.p.m. in the latter.

In general, the distribution of total phosphorus in the Planosol soils resembled that in the Prairie soils. The distribution in the Gray-Brown Podsolic soils differed considerably from that in the other groups, particularly in that the zone of minimum phosphorus content occurred nearer the surface.

Dilute acid-soluble phosphorus also decreased with depth to a minimum in the lower A or upper B horizon, and then increased markedly in subsequent layers to a maximum in the C horizon. The content and distribution of dilute acid-soluble phosphorus in the Planosol soils is quite similar to that in the normal Prairie soils developed from loess. In the Gray-Brown Podsolic soils the increase with depth begins at a point nearer the surface and is more gradual than in the Prairie soils formed from loess.

Much larger quantities of easily soluble phosphorus were found in the C horizons of the Prairie soils developed from loess than in those formed from glacial till; the maximum amounts present in the former were generally higher than 200 p.p.m. as compared with less than 60 p.p.m. in the latter.

No consistent relation was found between pH and the dilute acid-soluble phosphorus content of the soils.

In seven of the 12 soils studied more than 25% of the total phosphorus present in the lower layers was soluble in dilute acid, and in one soil 55% was soluble, as compared with 0.94 to 3.63% soluble in the surface layers.

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EFFECT OF TIME OF SEEDING ON YIELD, MILLING QUALITY, AND OTHER CHARACTERS IN RICE[1]

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GROWERS are vitally interested in information on the best date for sowing rice (*Oryza sativa* L.) in order to obtain maximum yields per acre of high milling quality. It is especially important, as has been pointed out (6),[3] to know how new varieties and selections react when sown on different dates.

In response to date of seeding and environment, rice varieties may be grouped as "indifferent" or "sensitive." When sown early in the spring, the "indifferent" varieties head and mature in the summer or early fall, whereas the "sensitive" varieties do not usually head and mature until fall. Jenkins (6) classed the "indifferent" varieties as having a "fixed growing period" able to head and mature during longer photo periods, while the "sensitive" varieties, described by Nelson (10) as having "a marked power of adaptation," head and mature during the shorter fall days. The growth period of all varieties is shortened to some extent when sowing is delayed, but varieties differ in degree of response and this difference in response is heritable and one of the outstanding characteristics of rice varieties. A date of seeding experiment in nursery plots was started at the Rice Branch Experiment Station, Stuttgart, Ark., in 1932 to obtain additional information on the effect of seeding date on the yield, growth, and quality of rice varieties. The results are reported in this paper.

MATERIAL AND METHODS

A total of 15 varieties and selections of rice, sown on four or five dates each season, was tested in 1 to 8 years. Eight varieties were grown each year from 1932 to 1936 and 10 varieties thereafter. The varieties were sown on five dates at approximately 15-day intervals each year from 1932 to 1936. After 1936 the late April seeding was omitted and seedings were made on only four dates.

Most of the varieties grown have been described in the literature. The short-grain varieties, Caloro and Colusa, were described by Jones (8), Acadia by Chambliss and Jenkins (2), and Jones (9) has described briefly the other varieties grown in this experiment, with the exception of Early Rose, Zenith, Arkansas Fortuna, Kameji, and the four hybrid selections.

Early Rose is an early-maturing, medium-grain variety selected by a rice grower in Arkansas. It was grown commercially in Arkansas for a year or two, then discarded. Zenith is an early-maturing, medium-grain variety selected in Arkansas in 1931 from a field of Blue Rose. Arkansas Fortuna is a long-grain variety selected from Fortuna and is the same as Fortuna except that it matures from 7 to 10 days earlier. Kameji is a midseason, short-grain variety.

The four hybrid selections grown were developed at Stuttgart, Ark., from crosses Caloro × Blue Rose, Kameji × Blue Rose, Edith × Fortuna, and Im-

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[3]Figures in parentheses refer to "Literature Cited", p. 706.

proved Blue Rose × Fortuna. They were selected from segregating F_2 and F_3 generations in the material received from the Biggs Rice Field Station, Biggs, Calif. The selections Caloro × Blue Rose (A. H.-29-19)[4] and Kameji × Blue Rose (A. H.-29-128) are midseason, medium-grain types, and Edith × Fortuna (A. H.-28-24) and Improved Blue Rose × Fortuna (A. H.-29-39) are midseason, long-grain types.

The varieties were grown in triplicate, systematically-replicated 3-rod row plots from 1932 to 1936 and in quadruplicate, randomized 3-rod row plots from 1937 to 1939. The standard deviation for grain yields in the systematically replicated plots was computed by the deviation from the mean method as suggested by Hayes (5) and the analysis of variance method for the randomized plots. An average standard error of the mean, in percentage, was computed for each date of seeding. These values were obtained by the formula $1/N \sqrt{a^2+b^2+c^2 \text{——} n^2}$, where N equals the number of values averaged and a, b, c —— n represent the values for the standard error of the mean for each year. An average standard error of the difference for each date of seeding was obtained by multiplying the average standard error of the mean for the years grown by $2\sqrt{2}$.

The yields were recorded after the rough rice was cleaned so as to be comparable to the commercial product. The yield of straw was obtained by subtracting the weight of the threshed grain from the weight of the total crop before threshing. Plant height was measured from the surface of the soil to the tip of the panicle.

Milling quality was determined by means of a Smith shelling device as described by Smith (11) and the separations were made by the method outlined by Boerner, *et al.* (1). The estimated yield of "head rice" and "total rice" was obtained from tables computed by W. D. Smith and his co-workers for that purpose. Smith, *et al.* (12, p. 2) define "head rice" as "milled rice consisting principally of whole kernels." "Total rice" is "head rice" plus all broken grains obtained in the milling process. The yields of "total rice" are not reported because the date of seeding did not seem to influence this character to any great extent.

The results for all factors studied are given in Table 1.

RESULTS

TIME OF MATURITY

Based on the manner in which the varieties reacted when sown on different dates, they are placed in two groups: (a) "Sensitive" varieties that showed a gradual but marked decrease in the number of days required to reach maturity when sown on successively later dates, and (b) "indifferent" varieties that showed a small but less consistent shortening of the growth period as sowing was delayed. Those in group 1 include Caloro, Colusa, Acadia, Supreme Blue Rose, Caloro × Blue Rose (A. H.-29-19), and Kameji × Blue Rose (A. H.-29-128), in which the reduction in the period from seeding to maturity from the first to the last date of seeding was 18 to 26%. Group 2 includes Early Prolific, Early Rose, Zenith, Storm Proof, Arkansas Fortuna, Nira, Edith × Fortuna (A. H.-28-24), and Improved Blue Rose × Fortuna (A. H.-29-39), in which the reduction in the period from seeding to maturity between the first and last or next to the last date of seeding was from 9 to 15%. The first four

[4]Hybrid selection numbers of the Rice Branch Experiment Station, Stuttgart, Ark.

varieties listed in group 2 required a longer growing period for the last date than for the preceding date of seeding.

When sown about the middle of June, Arkansas Fortuna failed to mature in 6 of the 8 years and Nira matured grain in 1939 only. Rexoro is a very late variety (group 2) and not suited for growing in Arkansas but usually matured a fair crop when sown in April. In this experiment it failed to reach full maturity when sown May 15 or later.

In some varieties, including Caloro, Colusa, Acadia, and Supreme Blue Rose, the length of the growing period was much reduced by late seeding and they matured when sown even as late as June 20. Other varieties, including Arkansas Fortuna, Nira, and Rexoro, showed less response to seeding date and did not mature from June sowing every year. Other "indifferent" or less responsive varieties, such as Early Prolific, Zenith, Early Rose, and Storm Proof, matured from June seeding. These results are in general agreement with those reported by Nelson (10), and Jenkins (6).

PLANT HEIGHT

Regardless of the date of seeding, none of the varieties grew so tall that it lodged or so short that it could not be harvested conveniently. The response in plant height to date of seeding differed, however, with the variety.

The varieties in group 1 that showed a gradual reduction in growing period when sown on successive dates also showed a gradual decrease in height from the first to the last date of seeding. The varieties in group 2 that showed a less marked reduction in the growing period were variable in height but, with certain exceptions, showed no consistent reduction in height due to delayed seeding. Edith × Fortuna (A. H.-28-24) and Improved Blue Rose × Fortuna (A. H.-29-39) showed a height reduction similar to that of the varieties in group 1 as did also Arkansas Fortuna, Rexoro, and Nira when they matured from the later dates of seeding.

The varieties that had the greatest shortening of the growth period (group 1) decreased in height in direct relation with the length of the growth period. In some of the "indifferent" varieties (group 2) the plants from the later dates of seeding were often taller than those from earlier seedlings.

All "sensitive" varieties reacted in the same manner with respect to plant height. The plants continued to increase in height until they headed during the shorter fall days; hence, when sown early, they had a longer growth period and were taller than when sown late. The "indifferent" varieties were variable in plant height and sometimes were taller when sown late than when sown early.

STRAW YIELD

Straw yields were obtained during the first 4 years of the experiment. The ratio of grain-straw was obtained by dividing the yield of straw by the yield of grain. A high yield of straw, unless accompanied by a correspondingly high yield of grain, increases the labor of har-

TABLE 1.—*Average growing period, plant height, yield, and milling quality of 15 varieties of rice sown at different dates.*

Variety or hybrid selection	C. I. No.[1]	Years grown	Average date sown	Period from seeding to maturity, days	Plant height, inches	Grain yield per acre: Total, lbs.	Grain yield per acre: Compared with Supreme Blue Rose, %	Estimated yield of head rice: Per barrel, lbs.	Estimated yield of head rice: Per acre, lbs.	Estimated yield of head rice: Difference from average of variety, lbs.	Acre yield of straw, lbs.	Straw grain ratio
"Sensitive," Group 1												
Caloro	1561-1	1932	Apr. 14	146	47	2,052	106.5	99	1,254	−363	5,995	2.92
		1932	Apr. 28	142	42	2,318	113.2	103	1,474	−143	4,447	1.92
		1932	May 14	131	41	2,525	125.8	107	1,668	+ 51	3,492	1.38
		1932	May 30	120	38	2,516	95.9	107	1,662	+ 45	3,498	1.39
		1932	June 17	108	37	3,159	204.7	104	2,028	+411	4,383	1.39
Colusa	1600	1932–36	Apr. 14	137	40	770[2]	45.5	91	432	−439	3,156	4.10
		1932–36	Apr. 29	126	38	1,121	66.0	92	637	−234	3,350	2.68
		1932–36	May 15	118	37	1,598	92.2	97	956	+ 85	4,102	2.45
		1932–36	May 29	115	37	1,998	112.1	99	1,221	+350	3,910	1.77
		1932–36	June 15	114	36	1,778	120.4	101	1,109	+238	3,942	2.17
Acadia	1988	1937–39	Apr. 22	154	44	1,908	134.2	102	1,202	+ 44	—	—
		1937–39	May 13	143	38	1,697	129.1	99	1,038	−120	—	—
		1937–39	May 31	132	35	1,805	135.9	100	1,114	− 44	—	—
		1937–39	June 20	120	34	2,030	142.7	102	1,278	+120	—	—
Supreme Blue Rose	5793	1932–39	Apr. 17	168	46	1,692	—	98	1,023	+ 44	4,594	2.31
		1932–36	Apr. 29	159	42	1,697	—	92	964	− 15	5,338	3.13
		1932–39	May 15	148	41	1,733	—	98	1,049	+ 70	6,330	3.10
		1932–39	May 30	138	41	1,782	—	97	1,067	+ 88	6,086	2.94
		1932–39	June 17	134	38	1,476	—	87	793	−186	5,676	4.38
Selection Caloro × Blue Rose (A. H.-29-19)	—	1937–39	Apr. 22	152	46	1,877	132.0	100	1,159	− 11	—	—
		1937–39	May 13	139	41	1,962	149.3	101	1,223	+ 53	—	—
		1937–39	May 31	132	38	1,706	128.5	99	1,042	−128	—	—
		1937–39	June 20	121	36	2,075	145.9	98	1,255	+ 85	—	—

Selection Kameji × Blue Rose (A. H.-29-128)	—	1938–39	Apr. 24	150	47	1,904	123.0	99	1,163	+ 40	—	—
		1938–39	May 10	140	42	1,625	128.5	98	983	−140	—	—
		1938–39	May 31	131	39	1,737	119.1	99	1,061	− 62	—	—
		1938–39	June 21	121	36	2,084	130.1	100	1,286	+163	—	—
"Indifferent," Group 2												
Early Prolific	5883	1932–39	Apr. 17	138	43	819[2]	48.4	85	430	−450	3,254	4.41
		1932–36	Apr. 29	130	40	1,377	81.2	85	723	−157	3,812	2.43
		1932–39	May 15	126	41	1,877	108.3	92	1,066	+186	4,930	2.17
		1932–39	May 30	124	42	2,147	120.5	94	1,246	+366	4,661	1.88
		1932–39	June 17	128	41	1,800	122.0	84	933	+ 53	5,175	3.04
Early Rose	—	1932–34	Apr. 13	134	37	1,283	56.0	94	744	−170	2,742	2.14
		1932–34	Apr. 28	124	34	1,170	63.4	91	657	−257	3,191	2.73
		1932–34	May 15	120	35	1,598	74.6	96	947	+ 33	4,430	2.81
		1932–34	May 30	118	37	2,052	88.0	98	1,242	+328	5,151	2.51
		1932–34	June 15	119	34	1,728	116.7	92	982	+ 68	6,382	3.69
Zenith	7787	1933–39	Apr. 17	139	43	891[2]	53.5	90	495	−415	2,688	3.62
		1933–36	Apr. 29	131	41	1,310	82.4	89	720	−190	3,278	2.22
		1933–39	May 15	126	41	2,007	118.6	94	1,165	+255	4,857	1.89
		1933–39	May 30	123	40	2,088	125.7	93	1,199	+289	4,361	1.75
		1933–39	June 17	126	39	1,899	129.4	83	973	+ 63	4,340	2.41
Arkansas Fortuna	—	1932–39	Apr. 17	151	48	1,670[2]	98.7	75	773	+ 60	3,710	2.03
		1932–36	Apr. 29	144	46	1,895	111.7	72	842	+129	3,122	1.58
		1932–39	May 15	141	47	2,187	126.2	69	932	+219	4,616	1.85
		1932–39	May 30	141	44	1,944	109.1	74	888	+175	4,515	2.32
		1932–39	June 17	129	40	441[3]	29.9	48	131	−582	4,891	2.79
Storm Proof	7705	1932–36	Apr. 14	139	45	1,179[2]	63.7	78	568	−207	3,732	3.17
		1932–36	Apr. 29	129	41	1,229	72.4	78	592	−183	4,118	3.00
		1932–36	May 15	123	44	1,854	93.6	82	938	+163	4,777	2.56
		1932–36	May 29	119	45	2,115	103.1	87	1,136	+361	4,661	2.18
		1932–36	June 15	128	43	1,755	116.4	59	639	−136	5,806	3.20

[1]Accession number of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. Agriculture.
[2]Not harvested because of very poor stands in 1936.
[3]Matured grain in 1933 and 1939.

TABLE I.—*Concluded.*

Variety or hybrid selection	C. I. No.[1]	Years grown	Average date sown	Period from seeding to maturity, days	Plant height, inches	Grain yield per acre: Total, lbs.	Grain yield per acre: Compared with Supreme Blue Rose, %	Estimated yield of head rice: Per barrel, lbs.	Estimated yield of head rice: Per acre, lbs.	Estimated yield of head rice: Difference from average of variety, lbs.	Acre yield of straw, lbs.	Straw/grain ratio
"Indifferent," Group 2—*Concluded*												
Rexoro	1779	1932–37	Apr. 15	193	46	1,103[4]	59.6	42	286	+111	6,131	5.20
		1932–36	Apr. 29	180	43	860[4]	50.7	42	223	+ 48	5,609	6.88
		1932–37	May 16	[5]	41	252[4,6]	12.7	11	17	−158	8,489	30.43
		1932–37	May 30	[5]	[5]	[5]	0	[5]	—	—	[5]	[5]
		1932–37	June 16	[5]	[5]	[5]	0	[5]	—	—	[5]	[5]
Nira	2702	1935–39	Apr. 19	164	49	1,692	127.0	54	564	+127	3,649	2.11
		1935–36	May 1	159	44	1,413	96.0	55	480	+ 43	3,492	2.69
		1935–39	May 14	152	49	1,899	128.3	48	563	+126	9,068	3.78
		1935–39	May 30	149	45	1,368[4]	94.1	64	540	+103	7,729	5.74
		1935–39	June 18	[5]	36	198[7]	13.5	30	37	−400	[5]	[5]
Selection Edith × Fortuna (A. H.-28-24)	—	1937–39	Apr. 22	137	45	1,085	76.3	88	590	−134	—	—
		1937–39	May 13	128	43	1,314	100.0	87	706	− 18	—	—
		1937–39	May 31	125	39	1,584	119.3	85	831	+107	—	—
		1937–39	June 20	120	37	1,683	118.4	74	769	+ 45	—	—
Selection Improved Blue Rose × Fortuna (A. H.-29-39)	—	1937–39	Apr. 22	137	42	1,382	97.2	85	725	−129	—	—
		1937–39	May 13	128	40	1,674	127.4	86	888	+ 34	—	—
		1937–39	May 31	129	36	1,710	128.8	86	908	+ 54	—	—
		1937–39	June 20	121	38	1,908	134.2	76	895	+ 41	—	—

[1]Accession number of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. Agriculture.
[4]Did not mature in 1937.
[5]Not fully mature before first killing frost.
[6]Produced some immature grain in 1932, 1934, and 1936.
[7]Produced some immature grain in 1939.

vesting and threshing and may also further deplete the soil fertility. However, if rice straw should become of importance in industry, data on its yield would be important.

The grain-straw ratio for Caloro was high for the first date of seeding, lower for the second, slightly reduced in the third, and then remained about constant.

The ratios for the early varieties, Colusa, Early Prolific, Zenith, and Storm Proof, were high for the first date of seeding, decreased for the next three dates of seeding, and increased again for the last date of seeding. The ratio for Supreme Blue Rose and Early Rose was low for the first date of seeding, slightly higher for the next three dates, and materially increased for the last date of seeding. The ratio for Fortuna, Rexoro, and Nira was somewhat different from that of the other seven varieties because of the poor grain development from the later dates of seeding. The ratio for Fortuna was comparatively low for the first three dates and higher for the last two dates of seeding. The ratio for Nira and Rexoro increased from the early to the late dates of seeding.

The relatively high yields of straw from the early dates of seeding were due to an increase in height and number of leaves on plants that continued in a vegetative stage over a long period. Bird damage to the grain of very early maturing varieties increased the proportion of straw in the total crop. Rice that matures late in the fall usually has a relatively high percentage of sterile florets and this, combined with a very leafy growth from June seeding, caused the grain-straw ratio for this date to be higher for most varieties than when sown earlier. The late-maturing varieties from the later dates of seeding probably were not fully mature when harvested and this increased the proportion of straw.

Most of the varieties produced more straw in proportion to grain when sown in April than when sown in May or June.

GRAIN YIELD

The grain yield is the most important record from a date of seeding experiment. The yields in pounds per acre are given in Table 1. The average yield of each variety for each date of seeding also is expressed as a percentage of the average yield of Supreme Blue Rose sown on the same date in the same years. Supreme Blue Rose was used as a standard because it is the most important commercial variety grown in Arkansas and produced the most uniform yields for all dates of seeding.

The values for the standard error of the mean, in percentage, were 4.67 for the April 15 seeding, 7.02 for the April 28 seeding, 3.95 for the May 15 seeding, 3.67 for the May 30 seeding, and 2.92 for the June 15 seeding. The values for the standard error of the difference, in percentage, were 13.20 for the first date, 19.86 for the second, 11.17 for the third, 10.38 for the fourth, and 8.26 for the fifth. The second date of seeding covered only five years which makes the standard error difference somewhat higher.

Caloro was grown only one year and the results, while not conclusive, indicate that the yield of this variety does not drop with

delayed seeding. The yields of Colusa were significantly lower for the first three dates of seeding than for the last two. The yields of Acadia were significantly higher for all dates of seeding than those of Supreme Blue Rose. The yields of Supreme Blue Rose were about the same for the first four dates of seeding but significantly lower for the fifth date. Early Prolific and Zenith gave very low yields for the first two dates of seeding but relatively high yields from May seedings with a slight reduction from June seeding. Early Rose gave comparatively low yields from all seedings which indicates why it has been dropped from commercial production. The selection Caloro × Blue Rose (A. H.-29-19) was grown three and the selection Kameji × Blue Rose (A. H.-29-128) only two years. The yields of these selections for the years grown indicate that they do not fluctuate greatly with seeding date. The yields of Arkansas Fortuna were high for the first four dates of seeding and the yield from the May 15 seeding was significantly higher than that for the other seedings. The yields of Storm Proof were low when sown in April but relatively high for the last three dates of seeding. The yields of this variety from May 29 seeding were significantly higher than for other seeding dates. The yields of Rexoro were very low from all dates of seeding. Nira produced high yields when sown in April and early in May but low yields from the late May and June seedings because the crop failed to mature in some years. The selection Edith × Fortuna (A. H.-28-24) gave very low average yields when sown in April and early May during the three years but gave significantly higher yields when sown in late May and June. The selection Improved Blue Rose × Fortuna (A. H.-29-39) gave a low average yield when sown in April and high yields when sown in May and June.

The varieties in group 1 produced relatively high yields of grain from all dates of seeding, although the highest yields were obtained from seeding in May. The highest yields of Arkansas Fortuna and Nira were obtained when sown in late April or early May. Zenith (group 2) gave the highest yields of rough and head rice when sown the latter part of May.

As pointed out by Nelson (10) seeding the middle of April was usually too early to obtain good stands owing to cool weather and competition with weeds and grass. In California, under different environmental conditions, Dunshee (4) and Jones (7) reported higher yields from sowing in April than on later dates. In Louisiana, Chambliss and Jenkins (3) reported that rice sown May 28 gave higher yields than when sown either earlier or later.

The results indicate that the varieties and selections Caloro, Acadia, Supreme Blue Rose, Caloro × Blue Rose (A. H.-29-19), and Kameji × Blue Rose (A. H.-29-128) may be sown to advantage over a longer period than the other varieties tested. However, these varieties should not be sown too early in April or much later than June 1. The highest yields of rough and head rice were obtained from seeding the last of April and during May.

A knowledge of the best variety to sow at any given period is important. The data indicate that the varieties best suited for sowing in April and early May are Acadia, Nira, Arkansas Fortuna, Selection

Caloro × Blue Rose (A. H.-29-19), and Supreme Blue Rose, and for for sowing in late May and June, Acadia, Zenith, Selection Caloro × Blue Rose (A. H.-29-19), and Early Prolific.

MILLING QUALITY

Rough rice (paddy) is the product as it comes from the thresher. It consists of the kernel (caryopsis) enclosed by the hulls (lemma and palea). Milled rice consists of the kernel with the hulls, bran, and embryo removed. The term "milling quality" usually refers to the amount of milled unbroken (head) rice obtained from a given quantity of rough rice and this largely determines the price of the latter. From the data presented (Table 1) it appears that milling quality is influenced to some extent by date of seeding. Certain varieties had a poorer milling quality when they were sown early and reached maturity before September 15 than when sown later and matured in late September or early October. This occurred in Colusa, Early Prolific, and Storm Proof varieties, and to a less extent in Zenith. Grain from the earlier dates of seeding of the midseason and late varieties was of good milling quality. The Arkansas Fortuna, Nira, and Rexoro varieties from the later dates of seeding were of very low milling quality because they did not fully mature before frost. The best milling quality for Arkansas Fortuna and Nira was obtained from seeding the latter part of April to May 15.

Many rice varieties produce grain that is "chalky" or opaque rather than translucent in appearance and of low milling quality when they ripen too early in the fall. The inferior quality appears to be due in part to high temperatures during the ripening period. The undesirable effect of high temperatures during the ripening period, however, has not been demonstrated under controlled conditions, but every year that the temperatures were abnormally high in August the rice that matured at that time was of low milling quality. Almost all varieties are affected to a greater or less extent. Therefore, to obtain high yields of good milling quality, early varieties should not be sown before the middle of May. Zenith proved to be the best early variety for seeding the middle of May. However, Early Prolific, Selections Edith × Fortuna (A. H.-28-24), and Improved Blue Rose × Fortuna (A. H.-29-39) also yielded well when sown May 15. The highest yields of head rice per acre for these four varieties and selections were obtained from seeding the last of May.

SUMMARY

The results of a date of seeding experiment with 15 varieties of rice are reported.

In response to date of seeding the varieties grown were grouped as (a) "sensitive" or (b) "indifferent." The "sensitive" varieties showed a gradual but marked decrease, ranging from 18 to 26%, in the number of days required to reach maturity when sown on successively later dates, and the "indifferent" varieties showed a small but less consistent shortening of the growth period, ranging from 9 to 15%, as sowing was delayed.

The "sensitive" varieties showed a gradual reduction in height from the first to the last date of seeding, whereas the "indifferent" varieties were variable, and, with certain exceptions, showed no consistent reduction in height due to delayed seeding.

Most varieties produced more straw in proportion to grain when sown in April than when sown in May or June.

The highest yields for the "sensitive" varieties and Zenith were obtained from seeding in May, and for the "indifferent" varieties, Arkansas Fortuna, and Nira, late in April or early May.

Most of the early and midseason varieties produced rice of better milling quality when they matured late in September or early in October than when they matured before September 15.

The data indicate that for best yields Supreme Blue Rose, Acadia, Caloro × Blue Rose, Kameji × Blue Rose, Arkansas Fortuna, and Nira should be sown before Zenith, Early Prolific, Colusa, Edith × Fortuna, and Improved Blue Rose × Fortuna. If sown in this order, the early varieties will mature before the late varieties. If this schedule were followed, none of the varieties would mature during the hot weather, but all would usually mature before bad weather begins and frost occurs in the fall.

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SPACING EXPERIMENTS WITH CORN[1]

A. A. Bryan, R. C. Eckhardt, and G. F. Sprague[2]

IN IOWA, corn is commonly check planted in hills spaced about 42 inches apart in rows of the same spacing. Planting rates vary from two to four plants per hill. Less frequently corn is drilled using the same row spacings. In general, drilled plantings produce slightly larger yields, but the differences are not great. Little work has been reported on row spacings closer than normal. Hume, Center, and Hegnauer[3] reported data in 1908 indicating a slight superiority of 33×33 inch over 44×44 inch spacing of hills in northern Illinois at both the two- and three-kernel planting rate. In central Illinois the same relation held for the two-kernel planting rate but was reversed when three kernels per hill were used.

In recent years there has been considerable interest in the possibility of increasing corn yields by planting in rows spaced only 21 inches apart. Some farmers who have tried this practice have reported obtaining considerable increases in yield. In preliminary trials the Agricultural Engineering Section, Iowa Agricultural Experiment Station, cooperating with the Bureau of Agricultural Chemistry and Engineering, U. S. Dept. of Agriculture, compared yields from two hill spacings, *viz.*, 21×21 inches, 1 plant per hill and 42×42 inches, 4 plants per hill. Larger yields were obtained from the 21-inch spacings.

The results presented here were obtained during a four-year period and include a number of different spacings with several hybrids.

MATERIAL AND METHODS

The experimental designs, strains, and spacings of the hills within the rows have varied somewhat from year to year. The row spacings of 21 and 42 inches have been used each season. Spacings within the rows have ranged from 42 to 10.5 inches and the number of plants per hill from one to four. All plots were completely bordered to reduce competition effects. Plantings in 1936 were made at double rates and the plants later thinned to the desired stands. In later years the plantings were made at the desired rate and no thinning was done. The detail of each experiment is presented with the data.

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[1]Contribution from the Farm Crops Subsection, Iowa Agricultural Experiment Station, Ames, Iowa, cooperating with the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Agricultural Engineering Section, Iowa Agricultural Experiment Station cooperating with the Bureau of Agricultural Chemistry and Engineering, U. S. Dept. of Agriculture. Jour. paper J-781 of the Iowa Agricultural Experiment Station. Project No. 543. Received for publication June 26, 1940.

[2]Formerly Agronomist, Agent, and Agronomist, respectively, Division of Cereal Crops and Diseases; collaborators, Agronomy Section, Farm Crops Subsection, Iowa Agricultural Experiment Station.

[3]Hume, A. N., Center, O. D. and Hegnauer, Albert. Distance between hills of corn in the Illinois Corn Belt. Ill. Agr. Exp. Sta. Bul. 126. 1908.

EXPERIMENTAL RESULTS

1936 DATA

The 1936 tests included three hybrids (Iowa Hybrids 931, 939, and 13) and six spacings (42×42 inches, 21×29.4 inches, 21×24.5 inches, 21×21 inches, 21×18.375 inches, and 21×14.7 inches). The 42×42 inch spacing had four plants per hill, the remaining five spacings, in 21-inch rows, had single plants at the distances listed.

The experimental design was of the split-plot type. Each replication was divided into three blocks, each of which was subdivided into six sub-blocks. The three hybrids and the six spacings were assigned by lot to the blocks and sub-blocks, respectively. Twelve replications were used. The results are presented in Table 1.

TABLE 1.—*Acre yields in bushels of three hybrids grown at six different spacings in 1936.*

Space in inches between		No. of plants per acre (perfect stand)	Acre yields, bu.			Mean acre yields, bu.
Rows	Hills		Ia. 931	Ia. 939	Ia. 13	
42	42	14,224	30.2	39.2	51.0	40.3
21	29.4	10,160	33.6	48.5	55.8	46.0
21	24.5	12,192	33.1	41.3	54.9	43.1
21	21.0	14,224	28.4	40.8	55.6	41.6
21	18.375	16,256	27.7	37.5	52.8	39.3
21	14.7	20,320	23.8	35.2	52.4	37.1
Least significant difference, bu..........			6.06			3.5

The growing season of 1936 was unusually hot and dry and yields ranged from 23.8 to 55.6 bushels per acre. Light showers in August and heavy September rainfall were of material benefit to the late Iowa Hybrid 13, and of much less benefit to the earlier Iowa Hybrids 939 and 931. The analysis of variance indicates that the difference in yields between hybrids and between spacings is significant. The variety × spacing interaction is not significant. The number of barren plants and the percentage of damaged kernels increased with increasing thickness of stand. In general, the highest yields were obtained from those spacings having fewest plants per acre. However, comparing the normal with the 21×21 inch spacing, which has the same number of plants per acre, the mean difference in yield over all hybrids, 1.3 bushels, is not significant.

1937 DATA

The 1937 tests were similar to those conducted in 1936 except that one new spacing, 42×10.5 inches, was added. Yield trends were reversed (Table 2), the spacings having the higher number of plants per acre producing the larger yields. The season of 1937 was very favorable for corn production. The analysis of variance indicates that variety and spacing differences and the variety × spacing interaction were all highly significant.

TABLE 2.—*Acre yields in bushels of three hybrids grown at seven different spacings in 1937.*

Space in inches between		No. of plants per acre (perfect stand)	Acre yields, bu.			Mean acre yields, bu.
Rows	Hills		Ia. 931	Ia. 939	Ia. 13	
42	42	14,224	90.4	101.5	106.2	99.4
42	10.5	14,224	84.6	96.9	100.8	94.7
21	29.4	10,160	83.2	91.9	91.0	88.7
21	24.5	12,192	86.7	98.0	98.5	94.4
21	21	14,224	91.2	104.0	102.3	99.2
21	18.375	16,256	90.6	107.3	107.7	101.9
21	14.7	20,320	92.2	105.4	115.7	104.4
Least significant difference, bu...........				2.83		1.63

The significant variety × spacing interaction appears to be related to the effect of spacing on tiller production. All three of the hybrids tiller freely under favorable conditions, but this tendency is most marked in Iowa Hybrid 13. In the closer spacings tillering was suppressed and larger yields resulted. However, the increases in yield differed in degree for the three hybrids.

Three of the seven spacings have the same number of plants per acre. Within this group no spacing produced a significantly higher yield than the standard 42×42 inch spacing. Among the other four spacings, which differ in the number of plants per acre, one cannot separate exactly the effect of plants per acre and different spacings.

1938 DATA

In 1938 eight strains were included in the test, four open-pollinated varieties and four hybrids. The 21×24.5 inch spacing was discontinued and two new spacings were added, *viz.*, 42×31.5 inch and 42×21 inch. The design used was a two dimensional, quasi-factorial arrangement with two groups of sets and four replications. The yield data are presented in Table 3.

The year 1938 was favorable for corn production but less so than 1937, as indicated by the yields presented. A further indication of this is the fact that the spacings with more than 15,240 plants per acre produced the lowest yields. Of the spacings having 14,224 plants per acre, the 21×21 inch and 42×10.5 inch spacings produced significantly larger yields than the normal 42×42 inch spacing.

The analysis of variance for yields indicates that varietal and spacing differences were highly significant. The variety × spacing interaction was not significant. Strain differences for damaged kernels, moisture percentages, shelling percentage, and bushel test weight were significant, while spacing differences were not significant.

1939 TESTS

In 1939 one spacing (42×31.5 inch) was dropped, leaving seven different spacings. The four open-pollinated varieties and the early hybrid, Iowa Hybrid 931, were dropped and four new hybrids were added, making a total of seven hybrids. The experimental design used

was a 7×7 lattice square requiring four replications for balance. A total of eight replications were used, the second set of four replications being obtained by turning the first design through an angle of 90 degrees. The yield data are presented in Table 4.

The 1939 season was quite favorable, as evidenced by the large yields obtained. Among the four spacings having 14,224 plants per acre, the 21×21 inch spacing yielded significantly higher than the normal 42×42 inch spacing. There is a suggestion that slightly more plants per acre would have been preferable, as indicated by the large yield of the 21×18.375 inch spacing. The data also suggest that 20,320 plants per acre were too many.

The analysis of variance for yield indicates that strain and spacing differences were both highly significant. The seven hybrids did not behave similarly over all spacings, as indicated by a highly significant strain × spacing interaction.

In all four years some of the spacings used have varied from the standard, 42×42 inch, in number of plants per acre. When differences in yield were obtained, the difference in number of plants per acre complicates the interpretation. The relative amounts of the yield differences due to the differences in numbers of plants per acre and to the differences in row and hill spacings are not readily apparent from these experiments.

An attempt has been made to answer this question through an analysis of the covariance between yield and stand. In effect two stand corrections were made, the first for minor irregularities in stand within spacings and the second for the larger differences in stand among the different spacings. This second adjustment may be subject to some question, but since the average stand for all spacings differs from that used in the standard 42×42 inch spacing by only 580 plants per acre, it is believed that no serious bias is introduced.

When this method is applied to the 1939 data, the correlation coefficient for the error component is .208 and the regression of yield on stand .1059. Calculating the errors of estimate to provide a test of significance, we find that the mean square for error is reduced only slightly, from 6.59 to 6.33. The mean square for spacing differences is reduced considerably, from 32.87 to 20.68, indicating that a sizable portion of the spacing differences were related to stand differences. However, when the adjusted yields were calculated, it was found that mean yields were changed only slightly. The two spacings differing most widely from normal in number of plants per acre were changed the most by the adjustment process. As pointed out above, these changes may be questionable. However, neither before nor after adjustment are the yields of these spacings (10,160 and 20,320 plants per acre) significantly different from the standard. After adjusting yields on the basis of their regression on stand, the difference between the 42×42 inch and the 21×21 inch spacings is just significant, using odds of 20:1.

The average yields for the four-year period covering five different spacings is presented in Table 5. Two- and three-year averages for other agronomic characters also are presented in the same table. The yield comparisons of most interest involve the 42×42 inch and 21×21

TABLE 3.—*Acre yields in bushels of four open-pollinated varieties and four hybrids each grown at eight different spacings in 1938.*

Space in inches between		No. of plants per acre (perfect stand)	No. of kernels per hill	Acre yields, bu.								Mean acre yields, bu.
Rows	Hills			Kossuth Reliance	Steen Y. D.	Black Y. D.	Krug	Ia. 931	Ia. 939	Ia. 13	Ia. 3110	
42	42	14,224	4	68.5	68.3	74.0	70.2	61.5	79.9	77.0	91.7	73.9
42	31.5	15,240	3	62.4	74.0	77.7	69.0	63.8	87.9	89.4	98.1	77.8
42	21	14,224	2	65.4	71.0	77.5	61.3	65.5	73.0	77.9	93.1	73.2
42	10.5	14,224	1	61.5	63.3	63.7	58.8	74.6	87.3	98.6	101.1	76.1
21	29.4	10,160	1	72.0	64.7	80.1	72.1	63.9	76.5	88.4	102.4	77.5
21	21	14,224	1	66.3	74.8	63.2	67.9	69.9	91.9	87.5	97.4	77.4
21	18.375	16,256	1	54.8	54.9	64.3	59.5	60.8	70.0	71.6	87.7	65.5
21	14.7	20,320	1	59.9	60.1	57.6	57.0	63.3	66.1	71.9	96.6	66.6
Least significant difference, bu.				5.42								3.03

TABLE 4.—*Acre yields in bushels of seven double crosses grown in seven different spacings in 1939.*

Space in inches between		No. of plants per acre (perfect stand)	No. of plants per hill	Acre yields, bu.							Mean acre yields, bu.	
Rows	Hills			U. S. 13	U. S. 44	Ia. 939	Ia. 13	Ia. 3110	Ia. 3395	Ia. 3638	Observed	Adjusted
42	42	14,224	4	83.5	92.6	84.2	79.9	93.6	88.3	90.4	87.5	87.8
42	21	14,224	2	95.1	85.3	96.9	88.9	98.2	84.9	92.3	91.7	91.7
42	10.5	14,224	1	90.1	83.1	84.6	80.1	94.3	90.7	85.6	86.9	87.2
21	29.4	10,160	1	93.5	87.7	79.1	79.1	85.1	80.1	73.6	82.6	85.3
21	21	14,224	1	96.9	87.2	97.3	89.1	90.0	87.2	99.2	92.4	92.4
21	18.375	16,256	1	86.4	93.7	87.3	84.6	103.0	86.3	96.0	91.0	90.5
21	14.7	20,320	1	89.0	88.3	94.8	90.9	98.1	83.6	84.3	89.9	88.3
Least significant difference, bu.				11.4							4.1	

inch spacings. The difference in yield is 3.1 bushels, which is not significant, t equalling 1.85. The differences in moisture contents are not significant. Tillering exhibits a close relationship with number of plants per acre. The spacing having the fewest plants per acre (21×29.4 inch, with 10,160 plants) had the most tillers; the spacing with the largest number of plants per acre (21×14.7 inch, with 20,320 plants) had the fewest tillers. Other spacings were intermediate in tillering.

Planting rate also had a decided effect on the incidence of lodging. At the closest spacing, lodging was most severe, while the normal spacing had next to the least lodging recorded. The differences in lodging between the 42×42 inch spacing and the 21×21 inch or the closer spacings are significant at the 5% level. The effect of spacing on the number of ears per hundred plants or the number of ears per hundred-weight is what would logically be expected, with the largest number of plants per acre producing the smallest ears and the fewest ears per 100 plants. Test weight per bushel and shelling percentage do not differ significantly for different spacings.

DISCUSSION

The customary spacing of corn has been determined by trial and error on the part of farmers over a period of several decades. Before any change in planting practices is recommended any new spacing should exhibit a decided superiority to compensate for the cost of replacing planting, cultivating, and harvesting machinery. In the experiments reported here none of the spacings tried have been consistently superior to the normal 42×42 inch spacing in any important respect. The four-year average yield of the 21×21 inch spacing exceeded that of the 42×42 inch spacing by 3.1 bushels, which is a non-significant increase. Even if this difference were significant, it can hardly be considered a sufficiently large increase in yield to justify a change in common planting practices, especially as the normal spacing had a distinct advantage in lodging resistance.

The planting rate of 4 kernels per hill used here with the standard 42×42 inch spacing resulted in an expected stand of 14,224 plants per acre. This is a slightly heavier planting rate than is commonly used in Iowa. Robinson and Bryan[4] have shown that planting rates of this sort would result in increased yields over much of the state.

The experiments for the years 1937, 1938, and 1939 each included two or more hill spacings in 42-inch rows ranging from 42 to 10.5 inches apart. These and the 21×21 inch spacing all had the same expected number of plants per acre. None of these spacings has been consistently superior to the normal 42×42 inch spacing. This suggests that minor variations in hill spacing are not important when the number of plants per acre is constant.

SUMMARY

A number of corn hybrids and open-pollinated varieties were compared, using several different hill spacings. In two out of four years

[4]Robinson, J. L., and Bryan, A. A. Iowa corn yield test. 1926.

TABLE 5.—*Average agronomic data recorded for five spacings for a two-, three-, or four-year period, 1936–1939, inclusive.*

Space in inches between		No. of plants per acre (perfect stand)	Acre yield, bu.*	Moisture content of grain, %†	Plants producing tillers, %‡	Lodging grade§	No. of ears per		Bushel test weight, lbs.†	Shelling percentage†
Rows	Hills						100 plants‡	Cwt.‡		
42	42	14,224	77.3	16.1	4.3	1.3	95.3	211.6	57.0	84.3
21	21	14,224	80.4	15.7	9.5	1.5	96.2	197.8	56.9	84.1
21	29.4	10,160	76.3	16.4	25.8	1.1	108.9	167.4	57.1	83.7
21	18.375	16,256	75.5	16.4	5.2	1.8	90.6	216.0	57.0	84.1
21	14.7	20,320	75.5	16.2	2.4	2.1	84.5	265.7	56.7	84.2

*Four-year period, 1936–39.
†Three-year average, 1937–39.
‡Two-year period, 1937–38.
§Two-year period, 1938–39; the lower grades indicate less lodging.

the 21×21 inch spacing exceeded the 42×42 inch spacing by a significant amount. The difference between four-year averages for these two spacings, however, is not significant. The closer spacings consistently had more lodged plants than the wider spacings.

In general, it appears that no consistent and material advantage will result from spacings closer than now normally used. Within the comparisons involving the same number of plants per acre minor variations in spacing had little effect on acre yield.

GERMINATION OF FRESHLY HARVESTED SEEDS OF SEVERAL *POA* SPECIES AND OF *DACTYLIS GLOMERATA*[1]

V. G. Sprague[2]

THE freshly harvested seeds and fruits of many plants are characterized by a dormant period during which germination is greatly retarded or completely inhibited. Changes may take place after a storage period of several weeks or months which allow the seed to germinate normally. Flemion (3, 4),[3] Gassner (5), Harrington (6), Haut (8), Kearns and Toole (9, 10), Smith (12), and Toole (13) have shown that germination was increased by chilling the moistened dormant seed of several widely different species for varying lengths of time. Fivaz (2), Gassner (5), Harrington (7), Morinaga (11), and others have shown that non-dormant seeds often germinate better under daily alternation of temperatures than under constant temperatures.

In a cytogenetic or breeding study of any plant it is usually desirable to obtain successive generations as frequently as possible. This may necessitate germinating the seed as soon as it has been produced. In the cytogenetic program at the U. S. Regional Pasture Research Laboratory difficulty was encountered in obtaining adequate germination of freshly harvested seeds[4] of *Poa pratensis* L. several other *Poa* species, and *Dactylis glomerata L.* To develop simple technics which would induce prompt germination of the freshly harvested seed of these species, the following experiments were conducted.

EFFECT ON GERMINATION OF TIME AND TEMPERATURE OF STORAGE OF DRY SEED OF *POA PRATENSIS*

The open-pollinated seed used in these experiments was harvested on June 21, 1938, from six plants growing in the field nursery. Seed from three of the plants contained 12 to 13% moisture at the time of harvesting, while seed from the other three contained 24 to 33%. After the seed had air dried for two weeks the moisture content of all lots was between 10 and 11%. Germination tests in this and all subsequent experiments were conducted with samples of 50 seeds each placed in Petri dishes on blotters moistened with 0.1% potassium nitrate solution. The seeds were selected individually with tweezers to make certain that each was plump and well formed.

One sample from each of the six lots was placed on a moist blotter for germination at room temperature (22° to 26° C). The pretreat-

[1]A contribution from the U. S. Regional Pasture Research Laboratory, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, State College, Pa., in cooperation with the northeastern states. Received for publication July 2, 1940.

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[3]Numbers in parenthesis refer to "Literature Cited", p. 721.

[4]In this paper, "seed" is defined in the broad sense as the caryopsis plus adhering glumes.

ments consisted of storing dry samples from each of the six lots at temperatures of 43°, 22° to 26°, 0°, and −7° C for periods of 4, 8, 16, 32, and 64 days. At the end of each storage period the seeds were moistened with 0.1% potassium nitrate solution and placed at room temperature where they received north light. The percentage germination was recorded every three days for a four-week period and all germinated seeds were removed when counted.

Since no significant differences were shown in the germination of the six lots of seed which originally had differed in moisture content, the results from all of the seed lots were averaged (Table 1). It is evident that storage of the dry seed for any of the periods shorter than 64 days did not increase the percentage germination. The seed stored at 43° C for this latter period showed an increased germination (52%) when compared to the germination (22 to 33%) of those lots stored at the other temperatures. At the end of the four-week germination period the seed from all treatments was placed in a cold chamber at 7° C for 12 days and then returned to room temperature for three additional weeks. This uniform cold treatment increased germination to about 90%.

TABLE 1.—*Average germination of six lots of freshly harvested seed of Poa pratensis subjected to different temperatures for varying lengths of time.*

Pretreatment temperatures, °C	Pretreatment time, days													
	0		4		8		16		32		64		Average	
	A*	B†	A	B	A	B	A	B	A	B	A	B	A	B
43°	—	—	1	92	1	88	2	92	1	82	52	90	11.4	88.8
0°	—	—	0	84	1	91	1	91	1	89	22	88	6.2	88.6
−7°	—	—	0	91	2	91	1	90	2	90	30	91	7.0	90.6
22° to 26°	1	79	—	—	—	—	—	—	—	—	33	90	—	—
Average..			0.3	89	1.3	90	1.3	91	1.3	87	35.7	89.7	8.2	89.3

*Average percentage germination of six seed lots at the end of four weeks at 22° to 26°.
†Average percentage germination of the same six seed lots at the end of three additional weeks at 22° to 26° after the seed had been treated at 7° C for 12 days following the previous germination period of four weeks at room temperature.

EFFECT OF STORAGE TEMPERATURE ON MOISTENED SEED OF *POA PRATENSIS*

Additional seed was harvested from the same six plants on July 6, 1938. The moisture content of this seed ranged from 10 to 11%. The seed had been stored at room temperature for four weeks when the germination tests were begun. One dish from each lot was allowed to germinate at room temperature. Four additional samples from each lot of seed were placed on the moistened blotters and allowed to remain at room temperature for 24 hours. One dish from each lot was then placed at a temperature of 43° C, 7° C, 0° C, and −5° C for seven days, after which they were returned to room temperature. The percentage germination was recorded every three days for two weeks, at which time germination had almost stopped. At this time all lots

of seed were transferred to a temperature of $^{+}7^{\circ}$ C where they were allowed to remain 11 days before being again returned to room temperature. Germination percentages were recorded at three-day intervals for two weeks.

The six lots of seed used in each treatment were averaged (Table 2). It is evident that the dormancy of the moistened seed was not broken by seven days at room temperature (22° to 26° C), at 43° C, or at −5° C, but that at 0° C the dormancy was partially broken and that at 7° C the seed germinated very well. Following the second storage treatment at 7° C for 11 days, all samples had germinated over 90%, except those which had previously been subjected to −5° C. It appears that this temperature may have been low enough to injure the viability of some of the seed.

TABLE 2.—*Average germination of six lots of freshly harvested seed of Poa pratensis.*

Pretreatment of moist seed	Germination at 22° to 26° C two weeks after treatment, %	Total germination at 22° to 26° C two weeks after chilling ungerminated seed at 7° C for 11 days, %
None............	0	94
7 days at 43° C.....	0	93
7 days at 7° C......	75	92
7 days at 0° C......	39	96
7 days at −5° C.....	0	83

GERMINATION OF *POA PRATENSIS* SEED SIX MONTHS AFTER HARVESTING

Part of the seed harvested July 8, 1938, was stored at room temperature for six months. Samples of 50 seeds each were used to study the effects of various temperature and light conditions on germination. The conditions used and the percentage germination obtained with each are presented in Table 3. After six months the seed had apparently lost its dormancy since germination of 90% or over was obtained without cold treatment. Satisfactory germination was obtained at 15° C and at 10° C constant temperatures and at daily alternations of temperatures of 15° C to 30° C and 10° C to 30° C. A constant temperature of 5° C appears to be too low for rapid germination, as is evidenced by a germination of only 60% after four weeks. However, transferring these lots to room temperature for one week increased germination to 90%. Very little effect of light on the germination was observed in these studies. While the percentage germination was slightly lower in the lots receiving alternating 20° and 30° C in darkness than those receiving 20° C in darkness and 30° C for 6 hours in north light, those lots at 15° C and 10° C which were in continuous darkness (except for the time when the dishes were removed for counting) germinated as well as those under north light.

TABLE 3.—*Average germination of six lots of Poa pratensis seed after storage for six months at room temperature.*

Germinating conditions*	Germination end of two weeks, %	Germination end of four weeks, %
20°–30° C	93	94
20°–30° C dark	90	91
Room temperature (22° to 26° C)	89	90
15°–30° C	91	94
15° C, dark, 10 days; then 20°–30° C	87	94
15° C dark	90	94
10°–30° C	76	87
10° C, dark, 10 days; then 20°–30° C	88	93
10° C dark	84	94
5°–30° C	29	88
5° C dark, 10 days; then 20°–30° C	0	90
5° C dark	0	60†

*The lower temperature was maintained in darkness and the higher temperature in north light, except where otherwise stated.
†One week at 22° to 26° C increased germination to 90%.

COMPARATIVE EFFECT OF CONSTANT LOW TEMPERATURES AND ALTERNATING TEMPERATURES IN INCREASING GERMINATION IN FRESHLY HARVESTED SEED OF *POA PRATENSIS*

On March 15, 1939, seed was harvested from several clones of *Poa pratensis* growing in the greenhouse. The seed was threshed, composited, and allowed to air-dry for one week before being sampled and placed on moistened blotters. All samples of seed were allowed to remain at room temperature for 24 hours to absorb moisture before they were subjected to the following temperature treatments: (a) 20° to 30° C; (b) 20° to 30° C (in darkness at both temperatures); (c) room temperature; (d) 15° to 30° C; (e) 15° for 10 days, then 20° to 30° C; (f) 10° to 30° C; (g) 10° for 10 days, then 20° to 30° C; (h) 5° to 30° C; (i) 5° C for 10 days, then 20° to 30° C. The low temperature interval was 18 hours in the dark and the high temperature interval was 6 hours in north light except in b.

Triplicate samples in each treatment were used and the number of germinated seeds recorded every three days. The results of these treatments are summarized in Table 4. It is evident from these data that at alternating temperatures of 15° to 30° C and 10° to 30° C much better germination was obtained than at 20° to 30° C or 5° to 30° C. They further indicate that alternating temperatures are much more effective than low temperatures for a continuous period of 10 days, except at the lowest temperature of 5° C, where the relationship appears to be reversed. Light during the 30° C period seemed to have little effect in aiding germination as is evident in comparing the 20° to 30° C series in light and continuous darkness.

GERMINATION OF FRESHLY HARVESTED SEED OF FOUR *POA* SPP.

A small quantity of open-pollinated seed was available in March 1939 from greenhouse plants of each of the following species: *Poa*

TABLE 4.—*Germination of freshly harvested seed of Poa pratensis composited from greenhouse plants.*

Germinating conditions*	Total germination at†		
	2 weeks %	4 weeks %	6 weeks %
20°–30° C	0	3	5
20°–30° C dark	1	9	11
Room temperature (22° to 26° C)	0	0	1
15°–30° C	11	47	77
15° C, dark, 10 days; then 20°–30° C	5	9	10
10°–30° C	14	87	91
10° C, dark, 10 days; then 20°–30° C	7	9	13
5°–30° C	0	4	5
5° C dark, 10 days; then 20°–30° C	0	28	29

*The lower temperature was maintained in darkness and the higher temperature in north light, except where otherwise noted.
†Each figure is the average of three replicates.

compressa L, *P. palustris* L, *P. alpina* L, and *P. arachnifera* Torr. One 50-seed sample of each species was subjected to an alternating temperature of 20° C for 18 hours in the dark and 30° C for 6 hours in north light, the germinating conditions recommended (1) in general for forage grasses. A second set of samples was given a 10-day cold treatment at 10° C in the dark before being subjected to the 20° to 30° C alternating temperatures (Table 5). With these species the percentage germination was increased by a temperature of 10° C for 10 days followed by alternating temperatures of 20° to 30° C. *Poa*

TABLE 5.—*Germination of freshly harvested seed of several Poa species from greenhouse plants, open-pollinated seed of several plants within each species composited.*

Species	Germinating conditions*	Germination at end of				
		1 week %	2 weeks %	3 weeks %	4 weeks %	6 weeks %
Poa compressa	20°–30° C	14	42	68	68	84
Poa compressa	10° C dark, 10 days; then 20°–30° C	6	66	80	84	84
Poa palustris	20°–30° C	26	54	84	84	86
Poa palustris	10° C dark, 10 days; then 20°–30° C	6	82	98	100	100
Poa alpina	20°–30° C	0	0	0	0	0
Poa alpina	10° C dark, 10 days; then 20°–30° C	66	98	98	98	98
Poa arachnifera	20°–30° C	0	0	0	0	0
Poa arachnifera	10° C dark, 10 days; then 20°–30° C	0	2	22	24	24

*The lower temperature was maintained in darkness and the higher in north light, except where otherwise noted.

alpina was perhaps most striking in its response to the lower temperture. Within 10 days it had germinated 94% at 10° C, whereas at the alternating temperature of 20° to 30° C it showed no evidence of germination, even after five weeks. The germination of all species increased at the lower temperatures, with the exception of *P. compressa*, which showed no improvement at the end of five weeks.

EFFECT OF TEMPERATURE ON GERMINATION OF FRESHLY HARVESTED SEED OF *DACTYLIS GLOMERATA*

During the summer of 1939 difficulty was experienced in obtaining good germination of freshly harvested seed of *Dactylis glomerata*. Open-pollinated seed from three clones in the field was placed under germinating conditions similar to those used with success on *Poa pratensis*. Samples of 50 seeds each were placed on moistened blotters and given the following treatments: (a) One sample of each clone at daily alternating temperatures of 22° to 28° C; one sample of each clone at each of the constant temperatures of (b) 15° C, (c) 10° C, and (d) 5° C for 14 days in darkness and then returned to 22° to 28° C conditions; and one sample of each clone at each of the daily alternating temperatures of (e) 15° to 28° C, (f) 10° to 28° C, and (g) 5° to 28° C. Inasmuch as no differential response of the three clones to germinating conditions was apparent, the results from the clones have been averaged (Table 6).

TABLE 6.—*Average germination of freshly harvested field seed of Dactylis glomerata.*

Germinating conditions*	Germination after two weeks, %†	Germination after four weeks, %†
22°–28° C	23	26
14 days at 15° C, then 22°–28° C	91	91
14 days at 10° C, then 22°–28° C	90	92
14 days at 5° C, then 22°–28° C	0	93
15°–28° C	96	96
10°–28° C	95	97
5°–28° C	39	95
Average	62	84

*The lower temperature was maintained in darkness and the higher in north light.
†Each figure is the average of duplicate samples of three clones germinated separately.

The germination of freshly harvested seed of *Dactylis glomerata* was increased when the moistened seed was subjected to a temperature of 10° to 15° C for a 14-day period and then removed to 22° to 28° C temperatures, or when the moistened seed was alternated daily between the low temperatures and 28° C. The alternation of low and high temperatures resulted in a slightly higher germination percentage than did constant low temperatures for a 14-day period followed by a temperature of 22° to 28° C.

SUMMARY

1. Freshly harvested seed of *Poa pratensis* and *Dactylis glomerata* were dormant when subjected to the recommended (1) germinating temperatures of 20° to 30° C.

2. By subjecting moistened dormant field seed of *Poa pratensis* and *Dactylis glomerata* to temperatures between 5° and 15° C for a period of 10 to 14 days over 90% germination was obtained.

3. With greenhouse seed alternating temperatures of 10° to 30° C or 15° to 30° C increased germination more effectively than constant temperatures of 10° and 15° C.

4. Seed of *Poa pratensis* was not dormant six months after harvest. At this time the effects of light and various temperatures on germination were not marked.

5. Freshly harvested seed of *Poa compressa*, *P. palustris*, *P. alpina*, and *P. arachnifera* from greenhouse plants showed various degrees of dormancy in germination at alternating temperatures of 20° to 30 °C. Chilling the moistened seed at 10° C for 10 days before subjecting them to the higher alternating temperatures increased germination.

6. For germinating freshly harvested seed of the species studied the best treatment consisted of daily alternating temperatures of 10° to 30° C or 15° to 30° C with the lower temperature effective for 16 to 18 hours and the higher temperatures for 6 to 8 hours. Where daily alternation is impractical, as with large quantities of field-grown seed, storage of the moistened seed at 10° to 15° C for two weeks with subsequent removal to room temperature may produce acceptable germination.

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MANGANESE, COPPER, AND MAGNESIUM CONTENTS OF SOME COMMERCIAL FERTILIZERS[1]

C. E. MILLAR AND W. S. GILLAM[2]

THE need of supplying one or more of the nutrients, nitrogen, phosphoric acid, and potash to most soils to increase crop production has been recognized for over a century. The fertilizer industry has been developed on the basis of the insufficient supply of these nutrients in an available form in agricultural soils. In recent years, research in plant nutrition has directed attention to the requirement of plants for small quantities of other elements, as copper, manganese, and magnesium. Studies of the soil supply and the role in plant growth of the so-called minor elements have evoked considerable interest, as is evidenced by the voluminous literature on the subject. Since, in some localities, and under certain conditions, it has been found advisable to recommend the application of small quantities of some of these elements as a part of the fertilization practice, it seemed of interest to have some knowledge concerning the amounts of these elements present in commercial fertilizers in common use.

The present investigation was undertaken with this point in mind and sets forth the results obtained from analysis of 11 commercial fertilizers (2–12–6) for manganese, copper, and magnesium.

EXPERIMENTAL

The samples of commercial fertilizers used in this investigation were furnished by the state chemist, Mr. Wm. Geagley, and were portions of samples taken according to standard methods for use in persuance of his chemical control duties in the administration of the fertilizer licensing law.

TREATMENT OF SAMPLES

The equivalent of a 10-gram sample of the oven-dry fertilizer was placed in a casserole and 20 cc of 18 N sulfuric acid added. The mixture was then heated until the material was well charred. The solution was allowed to cool, 16 N nitric acid was added until violent reaction ceased, and the solution was again heated until the fertilizer was thoroughly charred. Again it was cooled, 16 N nitric acid added as before and the solution heated until thick fumes of sulfuric acid were evolved. This procedure was repeated until the solution became clear and remained so when strongly heated. The solution was then evaporated just to dryness, 200 cc of 6 N sulfuric acid added, and the solution boiled. The hot solution was then filtered, the residue was thoroughly washed with hot dilute sulfuric acid, and the filtrate and washings were made to volume and reserved for analysis.

[1]Contribution from the Soils Section of the Michigan Agricultural Experiment Station, East Lansing, Mich. Authorized by the Director for publication as Journal Article No. 459 (n.s.). Received for publication August 1, 1940.

[2]Professor and Assistant Professor of Soils, respectively.

To a fairly large aliquot of this solution 10 drops of thymol blue indicator were added (6).[3] While vigorously stirring the solution, ammonium hydroxide was added dropwise until the color changed from pink to yellow. The pH of this solution was approximately 2.8 and it was buffered by the addition of 25 cc of a 25% solution of ammonium acetate. At this stage a slight flocculent precipitate usually formed. The solution was then heated to 70° to 80° C, maintained at this temperature for 30 minutes, and allowed to stand until the precipitate settled. Finally, the solution was filtered and the precipitate was washed with hot 5% ammonium nitrate. The precipitate, consisting of iron and aluminum phosphates, was discarded. The filtrate and washings were combined, made to volume, and reserved for final analysis.

Calcium was removed from the above solution by double precipitation of the oxalate, after the method of Kolthoff and Sandell (4). The filtrates and washings from these precipitations were collected, evaporated to dryness, ignited, taken up in water, and made to volume. This solution was then analyzed for manganese, copper, and magnesium.

DETERMINATION OF MANGANESE

An aliquot of 50 cc of the test solution was placed in an Erlenmeyer flask along with 0.2 to 0.4 gram of solid potassium periodate and 10 to 15 cc of concentrated nitric acid (9). One cc of syrupy phosphoric acid was added and the solution was boiled for a few minutes and then cooled. The red to pink color began to develop on heating and reached its maximum on cooling. The solution was then transferred to a 100-cc volumetric flask and diluted to the mark. Finally, it was placed in an optical cell and read in a Fisher photometer.

The calibration curve for the instrument was obtained, with the aid of a Wratten green light filter No. 58, by treating standard solutions of manganese sulfate, as described above, and reading in the photometer. An excellent curve was obtained which readily permitted evaluation of concentrations of manganese ranging from 0.2 to 10 p.p.m.

DETERMINATION OF COPPER

A 50-cc aliquot of the test solution was transferred to a 250-cc separatory funnel and 1 cc of concentrated hydrochloric acid and 10 cc added of a solution containing 150 grams of citric acid per liter. Concentrated ammonium hydroxide was then added to the solution, dropwise, until just alkaline to litmus. Ten cc of 0.1% solution of sodium diethyl-dithiocarbamate (1) were then added and the total volume made up to 100 cc. The colored compound formed upon addition of the carbamate reagent was then extracted with carbon tetrachloride in three separate portions. These extractions were made by using two 5-cc and one 10-cc portions of carbon tetrachloride, accurately measured. After vigorously shaking each mixture and allowing the layers to separate the colored carbon tetrachloride solution

[3]Figures in parenthesis refer to "Literature Cited", p. 725.

was drawn off into a dry test tube, the three portions being collected in the same container. The combined fractions, totaling 20 cc, were then placed in a small optical cell and read in the photometer.

The concentration of copper was then determined from the calibration curve prepared from standard solutions with the aid of a Wratten blue light C-5 filter No. 47. The curve covered a range of 10 to 160 p.p.m. of copper.

DETERMINATION OF MAGNESIUM

Since aluminum, iron, and phosphorus were present in varying amounts, care was taken to insure their removal before magnesium was determined. Iron phosphate, aluminum phosphate, calcium phosphate, and magnesium phosphate have a minimum solubility (8) at pH 2.2, 3.7, 6.5, and 10, respectively, but when the solution contains a mixture of these constituents iron and aluminum phosphates precipitate out (6) at pH 2, and magnesium phosphate remains in solution until a pH greater than 7 is reached. For this reason, as previously pointed out, a portion of the original acid extract was carefully brought to pH 2.8. This insured precipitation of most of the iron, aluminum, and phosphorus, while magnesium remained in solution. If the phosphorus content of the solution is high, it can be removed by the addition of small quantities of iron, such as ferrous ammonium sulfate.

A small aliquot of the solution was placed in a 100-cc volumetric flask and the concentration of magnesium was determined colorimetrically by a method previously described (3).

Results of the analyses are presented in Table 1, while in Table 2 are summarized findings relative to the amounts of manganese, copper, and magnesium occurring in certain farm products.

TABLE 1.—*Manganese, copper, and magnesium contents of some commercial 2–12–6 fertilizers.*

Fertilizer No.	Mn expressed as pounds of anhydrous $MnSO_4$ per ton of oven-dry fertilizer	Cu expressed as pounds of $CuSO_4.5H_2O$ per ton of oven-dry fertilizer	Mg expressed as pounds of $MgSO_4.7H_2O$ per ton of oven-dry fertilizer
16339	0.014	0.0004	1.57
16341	0.004	0.0004	0.42
16345	0.012	0.00000014	4.56
16348	0.004	0.0000003	0.70
16353	0.016	0.0000003	0.47
16380	0.018	0.0004	17.73
16383	0.012	0.00000034	2.88
16416	Trace	0.00000064	6.02
16440	0.009	0.00000012	0.91
16444	0.010	0.00000056	0.45
16446	0.009	0.0000003	2.03

CONCLUSIONS

The data in Table 1 show that all samples of fertilizer contained determinable quantities of copper and magnesium and, with one

TABLE 2.—*Minor elements contained in certain farm products.*

Crop	Amount	Lbs. of Mn as $MnSO_4$*	Lbs. of Cu as $CuSo_4.5H_2O$†	Lbs. of Mg as $MgSO_4.7H_2O$‡
Corn........	40 bu.	0.034	0.044	14.78
Oats.........	40 bu.	0.13	0.034	9.41
Wheat.......	25 bu.	0.13	0.046	12.10
Rye.........	20 bu.	——	0.026	8.19
Barley.......	30 bu.	0.055	0.041	10.57
Soybeans.....	20 bu.	0.11	0.107	102.65

*Data from Schaible, *et al.* (7).
†Data from Elvehjem (2).
‡Data from Millar (5).

exception, of manganese. The quantities of the elements present in the samples studied were extremely variable and in no instance large. Magnesium occurred in larger quantities than either of the other two elements and manganese ranked second.

Compared to the quantities of these elements contained in normal yields of several commonly grown crops (Table 2) the amounts found in the fertilizers are quite small with the exception of the magnesium content of sample No. 16380.

As the usual application of fertilizer is a small fraction of a ton per acre it appears that the crop must depend very largely on the soil for the required amounts of the elements under consideration.

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NOTE

THE DISTRIBUTION OF CANADA BLUEGRASS AND KENTUCKY BLUEGRASS AS RELATED TO SOME ECOLOGICAL FACTORS[1]

MUCH controversy exists as to the factors which determine the distribution of Canada bluegrass, *Poa compressa* L., and Kentucky bluegrass, *Poa pratensis* L. The general consensus of opinion prevails that Kentucky bluegrass is best adapted to rich land soils, while Canada bluegrass may be found to dominate under a wider range of conditions. The investigation of Hartwig[2] concerning the incidence of these two Poas indicates that differences in chemical composition of the soil beneath the two species do occur.

In the vicinity of the Ohio Experiment Station, Canada bluegrass has been frequently observed growing on roadway cuts where the clay subsoil has been exposed by road construction. In many instances Kentucky bluegrass was found in an adjacent area on the surface soil above. In rare cases it was observed to be established on the roadway cut adjacent to Canada bluegrass. Observations of the soils under the two sod types suggested that Kentucky bluegrass inhabited the darker and more friable soil. In the analysis of paired soil samples from roadway cuts, the average percentage organic matter was 2.1 under Kentucky bluegrass as compared to 1.3 under Canada bluegrass, as shown in Table 1. This same trend was shown in percentage total nitrogen of the soils. The range in pH of the soils was from 6.0 to 7.3, little difference being obtained between the paired samples.

Pure stands of the two species growing adjacent to each other in pastures were difficult to locate. Unpaired soil samples collected in 1938 from sods, both pastured and unpastured, gave the same trends in organic matter as those of paired samples. The data are presented in Table 2. The pH values were in general higher under Kentucky bluegrass sods than under Canada bluegrass. Moisture equivalent determinations on these same soils gave no definite differences. Field moisture determinations made at definite intervals during the summer of 1937 on a few soils were higher in soils under Kentucky bluegrass than under Canada bluegrass. The great amount of variation existing in these unpaired samples places a question on the validity of the results under these conditions.

A number of observations were made in the course of the study which are of interest. Frequently Canada bluegrass was found growing in dense stands under maple trees along the highway. Away from the trees, Kentucky bluegrass dominated. It is not known whether this resulted from shading, soil moisture, or some other factor or a group of factors.

On first examination of roadway cuts, the position or direction of slope where sods were growing appeared to be a factor involved. Upon

[1]Joint contribution from the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, and the Agronomy Department, Ohio Agricultural Station, Wooster, Ohio.

[2]HARTWIG, H. B. Relationships between some soil measurements and the incidence of the two common Poas. Jour. Amer. Soc. Agron., 10:847–861. 1938.

TABLE 1.—*Analyses of soil samples from roadway cuts, 1939.*

	Kentucky bluegrass			Canada bluegrass		
Soil No.	pH	N, %	Organic matter, %	pH	N, %	Organic matter, %
1	6.5	0.08	1.5	6.7	0.07	1.1
2	6.9	0.07	1.5	6.8	0.05	0.7
3	6.9	0.08	3.1	6.9	0.05	0.9
4	6.9	0.09	1.6	7.0	0.06	0.9
5	7.2	0.07	1.0	7.2	0.06	0.6
6	7.0	0.08	1.5	7.2	0.04	0.2
7	7.1	0.10	1.7	6.6	0.07	1.1
8	6.6	0.13	2.1	6.7	0.10	1.7
9	6.2	0.11	1.9	6.1	0.13	2.6
10	6.8	0.09	3.0	6.8	0.08	1.1
11	6.0	0.13	3.2	6.0	0.08	1.2
12	6.6	0.10	1.7	6.6	0.13	2.3
13	6.2	0.19	3.4	6.6	0.11	1.8
14	7.1	0.15	4.8	7.0	0.08	1.3
15	6.8	0.12	2.1	6.9	0.08	1.1
16	7.3	0.17	3.1	7.3	0.10	2.1
17	7.2	0.09	1.7	7.2	0.07	1.2
18	6.9	0.07	1.1	7.1	0.03	0.3
19	7.2	0.06	1.1	7.3	0.10	1.9
20	7.1	0.08	1.3	7.3	0.08	1.5
Av.....		0.10	2.1		0.08	1.3

more detailed observation, both species were found growing on all types of slope regardless of direction or steepness. The factors responsible for the establishment of Kentucky bluegrass on the cuts are not definitely known. It was never found growing on new cuts or

TABLE 2.—*Analysis of soil samples from pastured and unpastured areas, 1938.*

Kentucky bluegrass				Canada bluegrass			
Soil No.	pH	Organic matter, %	Moisture equivalent, %	Soil No.	pH	Organic matter, %	Moisture equivalent, %
1	6.8	5.7	12.1	51	5.9	4.0	18.6
2	6.7	5.1	12.5	52	5.7	2.7	20.6
3	6.9	7.4	25.2	53	5.9	2.8	22.2
4	6.5	4.6	23.8	54	6.3	3.9	21.6
5	6.8	3.8	25.8	55	6.1	3.2	27.8
6	6.2	4.2	25.8	56	6.7	4.8	23.0
7	6.1	7.0	18.3	57	7.0	3.8	25.1
8	6.4	8.1	30.6	58	6.2	4.7	13.0
9	6.8	6.2	25.0	59	6.9	3.2	20.5
10	7.1	3.6	24.5	60	5.7	4.3	24.3
11	6.3	6.4	28.6	61	5.6	2.0	15.9
12	6.1	5.5	13.1	62	5.6	2.7	20.1
13	6.3	6.5	21.6				
14	6.4	3.0	17.1				
15	6.5	5.0	23.6				
Av.....		5.5	21.8	Av.....		3.5	21.0

on stony clay soil such as that where Canada bluegrass was frequently found dominating.

In an effort to elucidate the problem of differences in fertility of soils dominated by the two species, yields of plant parts were determined on six square-foot areas from broadcast plots of each species in the summer of 1939. Average yields of plant parts of Kentucky bluegrass were slightly higher than those of Canada bluegrass when compared on a dry weight basis. In the study it was observed that rhizomes of Kentucky bluegrass penetrated to a greater depth than those of Canada bluegrass.

The foregoing results and observations did not appear sufficient to warrant a complete publication. Since it was not feasible to continue with a thorough investigation, it seemed desirable to offer such information as was obtained, with the idea, that it might initiate further investigation.—JAMES M. WATKINS, *formerly of the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture;* G. W. CONREY, *Ohio Experiment Station;* and MORGAN W. EVANS, *Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, Wooster, Ohio.*

BOOK REVIEWS

A STUDENT'S BOOK ON SOILS AND MANURES

By E. J. Russell. New York: The Macmillan Company. Ed. 3. VIII + 296 pages, illus. 1940. $2.50.

THE first edition of this book was published in 1915 and was twice revised. In the present volume the text is again completely revised and very largely re-written making available new material along many lines. It is written at a time when the British national need for increased food production is especially urgent, so has as its aim the instruction of students and farmers in methods of securing the greatest returns from the soil through cultivation and manuring.

The first part of the book deals with matters of more fundamental nature such as plant and soil composition and their interrelations, organic matter, and the effect of climate on soil conservation. Part 2 deals with cultivation and the control of soil fertility, while part 3 has to do with mineral fertilizers, organic manures, lime, and methods of fertilizing various crops. A short appendix presents some data of field experiments, handy tables, and composition of a few crops.

The text is well arranged, interestingly written, and although primarily prepared for British agriculture, contains, like all the author's works, a great deal of value for the American student and farmer. (R.C.C.)

FRENCH-ENGLISH SCIENCE DICTIONARY

By Louis De Vries. New York: McGraw-Hill Book Co., Inc. VIII + 546 pages. 1940. $3.50.

COMPILED by the author, who is Professor of Modern Languages at Iowa State College, with the collaboration of members of the Graduate Faculty at Ames, this dictionary was planned and

started several years ago to assist candidates for advanced degrees in acquiring a reading knowledge of the French language. It corresponds in many respects to the recently published German-English Science Dictionary from the same source.

No claim to completeness is made for the dictionary, but it contains 43,000 entries, including terms of the agricultural, biological, and physical sciences, as well as many literary terms. Special attention has been given to the French irregular verb and its many forms. Also, some 500 common idioms have been included.

The book is well printed, bound in flexible covers, and is of a size to make a convenient reference work for the student's desk. (J.D.L.)

AGRONOMIC AFFAIRS

THE SOIL SCIENCE SOCIETY PROCEEDINGS

VOLUME 4 of the Soil Science Society PROCEEDINGS containing the papers presented at the New Orleans meeting in November, 1939, is now available. The volume contains 455 pages, is printed by letterpress, and is cloth bound. The price is $5.00, post paid, and orders should be sent directly to Dr. G. G. Pohlman, Treasurer of the Soil Science Society, Agricultural Experiment Station, Morgantown, W. Va.

TOBACCO FERTILIZERS

RECOMMENDATIONS for fertilizers for flue-cured tobacco grown on average soils in Virginia, North and South Carolina, Georgia, and Florida have been prepared by an Agronomy Tobacco Work Conference of representatives of these states and of the U. S. Dept. of Agriculture. Professor C. B. Williams of the North Carolina Experiment Station was Chairman of the Conference and Professor T. B. Hutcheson of the Virginia Experiment Station, Secretary.

The recommendations deal with analyses of mixtures and rates of application, neutral fertilizers, and fertilizers for plant beds. Mimeographed copies of the recommendations may be obtained upon application to Professor Hutcheson at Blacksburg, Va.

FILM STRIP FOR 1941

ANNOUNCEMENT has been made by the Extension Service of the U. S. Dept. of Agriculture that the contract for film-strip production for the fiscal year of 1940–41 has again been awarded to Photo Lab, Inc., Washington, D. C., and that the prices will be the same as those in effect the past year.

Included in the subjects dealt with in these film strips are soil conservation, farm crops, farm forestry, and plant diseases and pests. Further information on film strips and how to purchase them may be had by writing to the Extension Service in Washington.

NEWS ITEMS

Professor R. M. Salter, Associate Director of the Ohio Agricultural Experiment Station, has been appointed as Director of the North Carolina Agricultural Experiment Station. He succeeds Dean I. O. Schaub who has been Acting Director since Dr. R. Y. Winters resigned several years ago to accept a position in the Office of Experiment Stations.

Doctor L. D. Baver, Professor of Agronomy in charge of Soils, at the Ohio State University, will accompany Professor Salter as Head of the Department of Agronomy and Associate Director of the Agricultural Experiment Station. He succeeds Professor C. B. Williams who was retired July 1. The administration prevailed on Dr. G. K. Middleton to serve as Acting Head of Agronomy during the short interval between the retirement of Professor Williams and the completion of arrangements with Dr. Baver. Professor Salter and Dr. Baver will assume their new duties October 1.

Doctor N. D. Morgan, horticulturist at the North Louisiana Agricultural Experiment Station, has resigned to join the field staff of the American Potash Institute, with headquarters at Shreveport, La. In his new position he will carry on the educational program of the Institute in the Southwestern states, cooperating with state and college agricultural forces, the fertilizer trade, and growers, on problems of soil management involving the efficient use of fertilizer.

L. M. Thompson who for the past year has been Junior Soil Surveyor with the Soil Conservation Service in Texas returned to his position as Instructor of Agronomy with the Department of Agronomy of the Agricultural and Mechanical College of Texas on September 1, from which he had a year's leave.

H. E. Hampton, Instructor in the Department of Agronomy, Agricultural and Mechanical College of Texas, College Station, Texas, was granted a year's leave of absence to enter the University of Missouri where he began work toward his doctor's degree during the summer of 1940.

Doctor B. D. Wilson, research professor of soil technology at Cornell University and long an active member of the Society, died on September 5 as a result of injuries sustained in an automobile accident at Warren, Ohio, while returning to Ithaca, N. Y., following a visit to his home in Kentucky.

In the August number of the Journal it was incorrectly stated that Charles A. Rowles of the University of Saskatchewan was granted the Ph.D. degree in Agronomy and Plant Genetics at the University of Minnesota last June. Actually, he received the degree in Soils at the University of Minnesota.

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FACTORS INFLUENCING THE GERMINATION OF SEED OF *TRIFOLIUM REPENS*[1]

GLENN W. BURTON[2]

WHITE clover (*Trifolium repens* L.) when grown in the Southeast usually behaves as a winter annual. In early summer, after producing seed, most of the plants die and the seeds remain dormant until fall or early winter. The seeds then germinate, the seedling plants make their main growth in early spring, produce seeds, and die, thus completing their life cycle.

It has been observed that white clover seed planted early in the fall becomes established quicker and can be pastured earlier than white clover which has reseeded naturally. In average seasons white clover is a valuable source of winter pasturage in Florida and south Georgia, and since the earlier it becomes established the earlier it can be grazed, some men are making light seedings of commercial seed early in the fall instead of waiting for volunteer seedings to produce a stand. Since in unusually dry or very cold seasons these early seedings fail to survive or produce little if any winter pasturage, the practice of making early seedings involves certain risks which many men will not care to take. These observations indicate that a strain of white clover producing seed 20 to 30% of which will germinate early in the fall from natural reseedings may prove valuable in this area.

MATERIAL AND METHODS

In an effort to determine whether or not such strains might be present in the white clover breeding material at Tifton, Ga., seed was harvested from 93 plants, the strain-building progeny of 17 selections, in the first week in June, 1939. These seeds were stored at room temperature until August 9, 1939, when scarified (scarified uniformly with sandpaper) and unscarified seeds of these plants were germinated at 10°, 20°, and 30° C, approximate mean winter, fall, and summer air temperatures, respectively, at Tifton, Ga.

One hundred seeds of each treatment were germinated in miniature "rag-doll" testers made of paper towelling labelled with India ink. The germination tests on

[1]Cooperative Investigations of the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, the Georgia Coastal Plain Experiment Station, Tifton, Ga., and the Georgia Experiment Station, Experiment, Ga. Received for publication June 17, 1940.

[2]Geneticist, U. S. Dept. of Agriculture, Tifton, Ga.

unscarified seed were run in duplicate. All samples germinating at any one temperature were placed together at random in a specially constructed moist chamber. Germinated seeds were counted and removed on August 16, 23, and 31 and on September 6. Due to the large volume of this germination data only a summary showing the general effect of scarification and temperature upon the seed of these 93 strains has been presented in Table 1.

RESULTS AND DISCUSSION

Table 1 shows that at the end of 28 days the freshly harvested unscarified seed germinated 3.1, 3.6, and 64.3% at 30°, 20°, and 10° C. That a change favoring germination occurred within the seed only at 10° is worthy of note. Samples of the same seed when scarified germinated 70.7, 89.9, and 95.3%, respectively, at the above temperatures. While most of the samples varied little from these mean values, unscarified seed of one selection germinated 4.5% at 30° and 14.5% at 20°.

The fact that scarified seed germinated an average of 70.7% at 30° C. indicates that the principal factor inhibiting the germination of unscarified seed at 20° and 30° was removed by scarification. Since the germination of scarified seed at 30° was significantly lower than at 20° and 10°, it would seem that 30° was too high for the most satisfactory germination.

TABLE 1.—*The average germination of scarified and unscarified seed of 93 selections of Trifolium repens held in germinators at 10°, 20°, and 30° C.**

Length of germination period, days	Percentage of unscarified seed germinated at			Percentage of scarified seed germinated at			Least significant difference	
	30° C	20° C	10° C	30° C	20° C	10° C	1% point	5% point
7	0.7	2.7	21.9	44.7	87.7	87.0	5.2	4.0
14	1.7	3.1	44.5	63.6	88.4	92.1	5.8	4.4
21	2.4	3.4	58.1	68.8	89.3	93.4	6.1	4.6
28	3.1	3.6	64.3	70.7	89.9	95.3	5.7	4.3

*This study was begun two months after the seed was harvested.

GERMINATION FOLLOWING COLD STORAGE

In an effort to explain why the differences presented above were obtained, seed of four strains of white clover which had responded differently in the first test were studied in some detail 7 months after harvest. During the 5-month period between these two studies the seeds were stored in a room with the relative humidity ranging from 60 to 100% and temperatures ranging from 5° to 15° C. Fitting this study to a factorial design, duplicate samples of scarified and unscarified seed of each strain were germinated at 10°, 20°, and 30° C in the same manner as in the previous study. To determine the effect of the temperature and scarification treatments on the rate of water absorption each 100 seed sample was weighed before and 5, 29, and [illegible] hours after it was placed in the germinators.

The weight increase data and the mean squares of the analysis of variance of it are presented in Tables 2 and 3. Table 3 shows that at the end of 5 hours seed treatment and temperature were the only significant sources of variation. The data revealed that scarified seed absorbed 9.2 times more water than unscarified seed in the initial 5-hour period. Water absorption at 10° and 20° was essentially the same, but at 30° the seeds absorbed 35% more water than at the two lower levels.

TABLE 2.—*The influence of temperature and scarification upon the relative increase in weight of seed harvested from four selections of white clover in 1939 and stored for five months in a room with the relative humidity near 100% and temperatures ranging from 5° to 15° C.*

Strain No.	Average percentage weight increase of all samples germinated at the temperatures indicated						Average percentage weight increase of all samples receiving the treatment indicated			
					Mean					
	No. of observations	10° C	20° C	30° C	No. of observations	All temperatures	No. of observations	Seed scarified	Seed not scarified	Difference*
Percentage Weight Increase 5 Hours After Seed Was Placed In Germinators										
2–34	4	23.3	26.6	28.8	12	26.2	6	46.1	6.4	39.7
2–56	4	24.4	24.4	32.2	12	27.0	6	51.0	3.1	47.9
3–108	4	23.9	20.0	38.4	12	27.5	6	49.9	5.0	44.9
7–75	4	22.4	23.6	27.5	12	24.5	6	43.0	6.1	36.9
Mean	16	23.5	23.7	31.8	48	26.3	24	47.5	5.1	42.4
Percentage Weight Increase 29 Hours After Seed Was Placed In Germinators										
2–34	4	56.4	76.8	98.5	12	77.2	6	88.6	65.8	22.8
2–56	4	59.8	64.1	84.7	12	69.6	6	86.2	53.0	33.2
3–108	4	61.0	78.2	93.7	12	77.6	6	91.4	63.9	27.5
7–75	4	42.7	50.3	58.6	12	50.6	6	79.0	22.1	56.9
Mean	16	54.9	67.3	83.9	48	68.7	24	86.3	51.2	35.1
Percentage Weight Increase 47 Hours After Seed Was Placed In Germinators										
2–34	4	69.4	102.3	164.1	12	111.9	6	127.4	96.4	31.0
2–56	4	77.6	84.8	110.4	12	90.9	6	108.2	73.7	34.5
3–108	4	85.6	103.9	130.6	12	106.7	6	123.4	90.0	33.4
7–75	4	60.8	76.1	92.1	12	76.3	6	120.5	32.1	88.4
Mean	16	73.3	91.8	124.3	48	96.5	24	119.9	73.1	46.8

*The least significant mean difference at the 5% point between means of 4, 6, 12, 16, and 24 observations for weight increase after 5 hours is 9.8, 8.0, 5.6, 4.9, and 4.0%; for weight increase after 29 hours is 10.3, 8.4, 5.9, 5.1, and 4.2%; for weight increase after 47 hours is 24.7, 20.2, 14.2, 12.3, and 10.0%, respectively.

After 29 hours it is evident from Table 3 that strains, temperature, and seed treatment varied significantly in weight increase. At 10°, 20°, and 30° the total relative weight increase for the four strains was 100.0, 122.7, and 152.8%, respectively.

Although at the end of 5 hours the scarified seed had a weight increase which was 9.2 times greater than that of the unscarified seed,

after 29 hours it was only 69% greater than the unscarified-seed. Since the weight increase for the 24-hour period was only 82% of the increase for the first 5-hour period, it is apparent that the rate of water absorption decreased rapidly as the scarified seeds approached saturation.

TABLE 3.—*Analysis of variance on a study of the increase in weight of scarified and unscarified seed of four Trifolium repens strains held in germinators at 10°, 20°, and 30° C.*

Source of variation	DF	Mean square of increase in weight of seed after		
		5 hours	29 hours	47 hours
Total	47	—	—	—
Strains	3	20.0	1930.4†	3070.0†
Temperature	2	355.7†	3371.3†	10627.9†
Treatment	1	21505.4†	14805.1†	26296.9†
Temperature×treatment	2	107.2	278.1†	505.7
Strains×temperature	6	54.1	145.5*	963.3†
Strains×treatment	3	74.0	685.6†	2315.9†
Strains×temperature×treatment	6	45.9	31.8	165.0
Error	24	45.0	49.8	287.5

*Significant.
†Highly significant.

The increase in rate of water absorption associated with a temperature increase caused the scarified seed to absorb increasingly greater quantities of water than unscarified seed at higher temperature levels. This accounts for the significant temperature × treatment interaction.

The nature of the strains × temperature interaction can be illustrated by the fact that at 20° and 30° selection 3-108 had total weight increases over that at 10° which were 60.5 and 90.5% greater than the corresponding weight increases for 7–75. Thus temperature increased the rate of water absorption in 3-108 more than in 7–75. This difference in rate of water absorption between 3–108 and 7–75 is probably due to the fact that 7–75 possessed a much larger percentage of "hard seeds" which had a very low rate of water absorption.

The highly significant strains × treatment interaction is easily understood in light of the fact that scarification at the end of 29 hours increased the water absorption in 3–108 and 7–75, 43.2 and 357.3%, respectively. Thus the percentage of hard seeds made permeable by scarification was much higher in 7–75 than in 3–108.

Since the temperature × treatment interaction was not significant after 47 hours, it is evident that the favorable influence of the higher temperature on the rate of water absorption was overcome as the seeds became saturated with water. All other relationships were essentially the same as described for the 29-hour period.

The percentage germination after 3, 7, 14, and 21 days was determined for each sample in this study. The data for the first three germination counts and the mean squares of the variance for the various sources of variation are presented in Tables 4 and 5.

It is interesting that after 3 days all sources of variation except the triple interaction were highly significant. Considering first strains and the interactions involving them, the data showed that the total germination for all samples of 3–108 was 63.7% greater than that of 7–75. For the first 3 days temperature increase had a greater effect upon the germination of 7–75 than on 3–108. This was probably due to the fact that 3–108, having a faster rate of water absorption, reached its requirements for germination so much earlier than 7–75 that the favorable influence of temperature on rate of water absorption was no longer expressed to the same degree in the germination response of 3–108 as it was in 7–75.

Since scarification increased the germination of the seed of 3–108 by 20.5% and increased the germination of 7–75 by 228.0%, the nature of the significant strains × treatment interaction is quite apparent.

TABLE 4.—*The influence of temperature and scarification upon the germination of seed harvested from four selections of white clover in 1939 and stored for five months in a room with the relative humidity near 100% and temperatures ranging from 5° to 15° C.*

Strain No.	Average percentage germination of all samples germinated at the temperatures indicated						Average percentage germination of all samples receiving the treatment indicated			
	No. of observations	10° C	20° C	30° C	Mean: No. of observations	Mean: All temperatures	No. of observations	Seed scarified	Seed not scarified	Difference*
Percentage Germination 3 Days After Seed Was Placed In Germinators										
2–34	4	13.5	65.0	76.0	12	51.5	6	59.2	43.8	15.4
2–56	4	24.5	60.0	66.8	12	50.4	6	55.3	45.5	9.8
3–108	4	15.2	72.8	73.0	12	53.7	6	58.7	48.7	10.0
7–75	4	6.8	41.5	48.0	12	32.1	6	49.2	15.0	34.2
Mean	16	15.0	59.8	65.9	48	46.9	24	55.6	38.2	17.4
Percentage Germination 7 Days After Seed Was Placed In Germinators										
2–34	4	68.7	68.0	78.0	12	71.6	6	80.7	62.5	18.2
2–56	4	71.0	67.8	71.2	12	70.0	6	79.9	60.2	19.7
3–108	4	84.0	82.7	79.2	12	82.0	6	86.0	78.0	8.0
7–75	4	47.5	48.0	53.2	12	49.6	6	72.9	26.3	46.6
Mean	16	67.8	66.6	70.4	48	68.3	24	79.9	56.8	23.1
Percentage Germination 14 Days After Seed Was Placed In Germinators										
2–34	4	70.0	69.2	78.0	12	72.4	6	82.2	62.7	19.5
2–56	4	75.5	68.8	74.2	12	72.8	6	83.8	61.8	22.0
3–108	4	85.5	84.8	81.5	12	83.9	6	88.5	79.3	9.2
7–75	4	49.5	49.8	53.5	12	50.9	6	74.7	27.2	47.5
Mean	16	70.1	68.1	71.8	48	70.0	24	82.3	57.7	24.6

*The least significant mean difference at the 5% point between means of 4, 6, 12, 16, and 24 germination counts after 3 days is 9.7, 7.9, 5.6, 4.8, and 4.0%; after 7 days is 7.8, 6.3, 4.5, 3.9 and 3.2%; after 14 days is 7.0, 5.7, 4.0, 3.5, 2.8%, respectively.

TABLE 5.—*Analysis of variance on a study of the germination of scarified and unscarified seed of four Trifolium repens strains held in germinators at 10°, 20°, and 30° C.*

Source of variation	DF	Mean square for germination of seed after		
		3 days	7 days	14 days
Total	47	—	—	—
Strains	3	1195.3*	2206.7*	2286.8*
Temperature	2	12374.0*	60.9	54.5
Treatment	1	3605.0*	6394.1*	7227.5*
Temperature × treatment	2	562.7*	159.6*	202.6*
Strains × temperature	6	178.3*	47.7	46.4
Strains × treatment	3	397.5*	811.7*	795.4*
Strains × temperature × treatment	6	98.1	29.7	33.2
Error	24	44.3	28.5	22.9

*Highly significant.

The fact that temperature and the strains × temperature interaction were not significant at the end of 7 days indicates that the principal effect of higher temperatures was to increase the rate of water absorption and growth, and that at the end of one week the total requirements had been reached at all temperature levels.

Comparing the total germination of all scarified and unscarified samples scarification increased the germination the first 3 days 45.3%.

The close relationships between water absorption as measured by weight increase of the seeds and germination indicates that the germination of white clover seed is dependent largely upon its ability to absorb water. The highly significant correlation coefficients of +.52, +.55, and —.73 obtained between the germination in 3 days and the weight increase of seed after 5, 29, and 47 hours lends weight to this conclusion. The fact that a fair percentage of commercial white clover seed is scarified and hence will absorb water readily probably explains why early fall seedings of commercial seed will germinate and become established earlier than natural reseedings.

The data showing the germination performance of selections 7–75 and 3–108, 2 and 7 months after the seeds were harvested is presented in Table 6. These data show in detail the previously discussed effects of temperature and treatment upon the germination of these two lots of seed. The new feature of particular interest presented here lies in the comparison of the germination response of strains 7–75 and 3–108, 2 and 7 months after harvest. It is quite apparent from the data presented in Table 6 that 5 months' storage in a room with a relative humidity from 60 to 100% and temperatures ranging from 5° to 15° C brought about changes in the seed which caused the unscarified seed to germinate much better at 20° and 30° than it had 5 months earlier.

In the case of 3–108 this change was so great that unscarified seed germinated about as well as scarified seed. Since scarified seed of 7–75 germinated much better than unscarified seed even after 5 months' storage, it is evident that this change in 7–75 was much less pronounced than in 3–108.

TABLE 6.—*The influence of scarification, temperature, and storage upon the germination of seed harvested from two selections of white clover in 1939.**

Germination temperature °C	Seed treatment†	Two months after harvest, germination percentage after				Seven months after harvest, germination percentage after			
		7 days	14 days	21 days	28 days	3 days	7 days	14 days	21 days
		Selection 7–75							
10	U	19.5	43.5	61.0	69.5	3.5	28.5	30.0	33.0
10	S	70.0	82.0	90.0	90.0	10.0	66.5	69.0	71.5
20	U	7.0	8.5	8.5	8.5	14.0	18.5	19.0	19.0
20	S	30.0	31.0	33.0	34.0	69.0	77.5	80.5	81.5
30	U	0.0	2.0	4.0	4.0	27.5	32.0	32.5	32.5
30	S	37.0	45.0	52.0	53.0	68.5	74.5	74.5	75.0
		Selection 3–108							
10	U	53.5	86.5	92.5	97.0	13.5	83.5	85.0	85.5
10	S	97.0	99.0	100.0	100.0	17.0	84.5	86.0	87.0
20	U	0.5	0.5	0.5	0.5	67.0	78.0	78.0	78.0
20	S	98.0	98.0	99.0	100.0	78.5	87.5	91.5	92.0
30	U	1.0	2.0	2.0	3.0	65.5	72.5	74.5	74.5
30	S	68.0	71.0	74.0	76.0	80.5	86.0	88.0	88.0

*After the first test the seed were stored in a room, with the relative humidity near 100% and temperatures ranging from 5° to 15° C.
†U = Unscarified; S = Scarified.

In an effort to explain why after 3 days unscarified seed of selection 2–56 germinated 68.0%, while unscarified seed of 7–75 germinated only 22.5%, a difference which existed throughout the test, the following comparisons were made of the seeds of these two selections: The weights of 12 100-seed samples of each selection revealed that the seeds of 2–56 with an average weight of 55.0 mgm per 100 seeds were significantly heavier than the seeds of 7–75 which averaged 41.2 mgm per 100 seeds.

Microscopic measurements of cross sections of the seed coat on 65 seeds of these two selections indicated that they did not differ significantly in seed coat thickness.

Using La Motte's Duplex indicator for soils, the pH of crushed light yellow seeds of these two selections was determined. The seed coats of both selections stained a deep red of the same intensity showing a pH of 4.0 or below. The cotyledons on both strains stained a yellowish orange indicating a pH of about 5.5.

Since 7–75 seemed to contain a higher percentage of red seeds than 2–56, red and yellow seeds were separated from the seed of 7–75 and were studied for rate of water absorption and germination. Although red seeds germinated slightly better than yellow ones, the difference was not significant.

Of these comparative measurements 7–75 and 2–56 differed significantly only in the weight of 100 seeds. Assuming the same density in both seed lots, the smaller seeds would have the greater surface or the greater seed coat area per unit of material contained

within. If the seed coats of large and small seeds were equally permeable, the small seeds should become saturated before the large ones. Since the seeds of 7–75 were smaller and were also slower in absorbing water and germinating than those of 2–56, it is evident that the seed coats of 7–75 were much more impermeable to water than the seed coats of 2–56. Whether this difference in permeability is due to the kind of fatty materials in the seed coat, the manner in which they are distributed or some other unrelated factors awaits the proof of intensive micro-chemical studies.

SUMMARY

1. Two months after harvest, unscarified seed of 93 selections of white clover, held in germinators at 30°, 20°, and 10° C for 28 days, germinated an average of 3.1, 3.6, and 64.3%, respectively. The same seed when scarified germinated 70.7, 89.9, and 95.3% at these temperatures. Thus it is apparent that the principal factor inhibiting germination of clover seed at 20° and 30° was removed by scarification. The average germination of the unscarified seeds suggests that some type of internal change comparable in effect to scarification of the seed coat occurs only at 10° C.

2. Five months storage at 5° to 15° C and at high relative humidities increased appreciably the germination at 20° and 30° C of unscarified seed of four of the selections that were tested.

3. Significant strain differences in response to cold storage, scarification, and temperature increase were noted.

4. Temperature increase hastened water absorption and germination but had little effect upon total germination.

5. Seed scarification increased the rate of water absorption, the rate of germination, and total germination in all four strains tested. The favorable effect of scarification was most pronounced when seeds were germinated at high temperature levels.

6. The highly significant correlation coefficients of +.52, +.55, and +.73 obtained between germination in 3 days and weight increase of seed after 5, 29, and 47 hours indicates that the germination of white clover seed is associated with its ability to absorb water.

7. Selections 7–75 and 2–56 which responded very differently to cold storage did not differ significantly in seed coat thickness, in pH of seed coat and cotyledon, or in percentage germination of red and yellow seeds. Seeds of 7–75, which were least affected by cold storage, were significantly smaller than the seeds of 2–56.

EFFECTS OF ROTATIONAL AND MANURIAL TREATMENTS FOR TWENTY YEARS ON THE ORGANIC MATTER, NITROGEN, AND PHOSPHORUS CONTENTS OF CLARION AND WEBSTER SOILS[1]

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IT HAS been observed quite generally that yields decline on soils soon after they are first brought under cultivation, especially where continuous cropping has been practiced. The decreased productivity has been ascribed to a depletion of the readily available plant food constituents, the changes in physical and biological conditions of the soil attendant upon cultivation, and the loss in organic matter. Numerous experiments under widely differing conditions as to soils, climate, and cropping systems have been conducted. Some of these experiments have been carried on over extended periods and much information has been obtained. White (11)[3] reported that on similarly treated soils there exists a close ratio between total yields of crops and the residual soil organic matter.

Salter and Green (6) presented data showing the changes in nitrogen and organic carbon in Wooster silt loam under continuous cropping and various rotations. It was estimated that a single year's cropping to the various crops increased or decreased the organic carbon content of the soil by the following percentages of the total amount present in the soil: Corn, −3.12; wheat, −1.44; oats, −1.41; hay in a 5-year rotation (timothy predominating), +1.36; and hay in a 3-year rotation (clover), +3.25. The corresponding values for nitrogen were: Corn, −2.97; wheat, −1.56; oats, −1.45; hay in a 5-year rotation, +0.64; and hay in a 3-year rotation, +2.87.

Blair and Prince (2) reported analyses of soils collected from cylinders and from field plats which had been cultivated and cropped for periods of 25 to 35 years and of soils collected in the beginning of the experiment. It was shown that continuous cropping even with fertilizer additions tended toward a depletion of the organic matter and nitrogen contents of the soil. There was an increase in the amount of phosphorus in the cultivated and fertilized soil and in one case the percentage of phosphoric acid was more than doubled in a period of 25 years.

Karraker (4) determined the gains and losses of nitrogen in variously treated plats during a 7-year period. He reported a loss of 530 pounds of nitrogen per acre in a soil kept bare, a gain of 62 pounds per acre under bluegrass, and a gain of 405 pounds in a soil under bluegrass and white clover.

Metzger (5) in a study of nitrogen and organic carbon of soils as affected by crops and cropping systems found that corn was more destructive of nitrogen and carbon than any other crop studied. Alfalfa and cowpeas added to the supply of soil nitrogen, but cowpeas were more destructive of soil carbon than alfalfa. Manure failed to produce significant increases in nitrogen or carbon above that which could be attributed to increased crop residues.

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[3]Figures in parenthesis refer to "Literature Cited", p. 752.

The effect of continuous cropping to corn for 19 years on the contents of organic matter, nitrogen, and phosphorus and on the pH of Clarion loam has been reported (8). It was found that considerable losses in organic matter, nitrogen, and phosphorus occurred even when relatively large applications of manure were made.

The purpose of the present study was to determine the effect of various soil treatments and of different crop rotations on the changes in the organic matter, nitrogen, and phosphorus contents of soils during a period of 20 years.

GENERAL PLAN OF EXPERIMENT

The 2-year, 3-year, and 5-year rotation plats which had been established at the Agronomy Farm near Ames in 1914 were selected for this study (9).

In these experiments every crop in the rotation has been planted each year. That is, replicate blocks with all treatments are planted to each crop each year. For example, the plats of the 2-year rotation are arranged in two blocks, the one planted to corn and the other to oats. Each block is divided into four 1/10-acre plats 28 feet in width and two 1/20-acre plats 14 feet in width. The plats are separated by 7-foot borders. The soil treatments made in each block of the 2-year rotation were as follows: (a) Check; (b) manure and lime; (c) manure, lime, and rock phosphate; (d) crop residues and lime; (e) crop residues, lime, and rock phosphate; (f) check. In this rotation the manure was added in 1914 and every other year thereafter at the rate of 4 tons per acre. The lime was added as ground limestone in 1914 and thereafter when necessary to neutralize the acidity of the soil. Rock phosphate was applied at the rate of 500 pounds per acre once in the rotation.

The plats under the 3-year rotation of corn, oats, and clover are arranged in three blocks, each containing six plats similar in size and shape to those in the 2-year rotation. The treatments made in each block were the same as those made in the 2-year rotation. The manure was applied at the rate of 6 tons per acre once in the rotation. Ground limestone was added as necessary to neutralize the acidity of the soil and the rock phosphate was applied at the rate of 750 pounds per acre once every 3 years.

The plats of the 5-year rotation, probably better designated as a modified 4-year rotation, are arranged in five blocks. Each block contains 11 1/10-acre plats 28 feet wide and 155.6 feet long and are separated by 7-foot borders. For 20 years a 4-year rotation of corn, oats, clover, and wheat is used, and for the next 5 years the plats are planted with alfalfa. The treatments made on the 11-plat blocks were as follows: (a) Check; (b) manure; (c) manure and lime; (d) manure, lime, and rock phosphate; (e) manure, lime, and superphosphate; (f) check; (g) crop residues; (h) crop residues and lime; (i) crop residues, lime, and rock phosphate; (j) crop residues, lime, and superphosphate; (k) check. The manure was applied at the rate of 8 tons per acre once every 4 years, except before the alfalfa seeding when it was applied at the rate of 10 tons per acre. Limestone was added to neutralize the acidity of the soil. The rock phosphate was applied at the rate of 1,000 pounds per acre once every 4 years, except before the seeding of alfalfa when 1,250 pounds per acre were applied. The superphosphate (20% P_2O_5) was applied at the rate of 120 pounds per acre to each grain crop in the rotation, except before the seeding of alfalfa when the rate was 300 pounds per acre.

The layout of the continuous corn plats and the plats of the 2-, 3-, and 5-year rotations is given in Fig. 1. The Roman numerals and letters in the figure refer to the block number.

The plats of the 2-, 3-, and 5-year rotations were sampled both in 1917 and in 1937. The 1917 samples consisted of five borings, one taken at each corner and one at the center of each plat. For the purpose of sampling in 1937 each plat was divided lengthwise into three sections, each approximately one-third the width of the plat. Three borings approximately 50 feet apart were taken from each section,

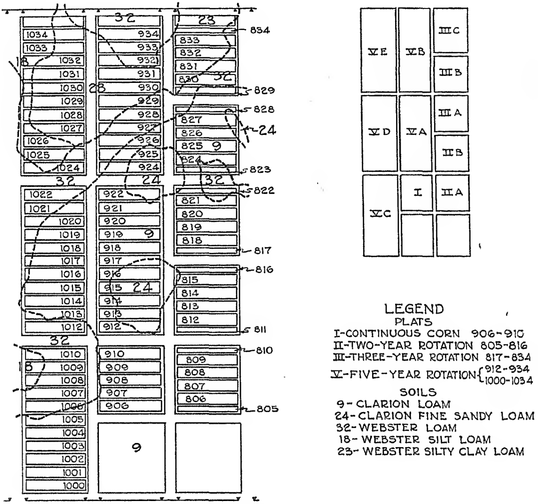

FIG. 1.—Rotation experiments, Agronomy Farms, Iowa State College, Ames, Iowa.

starting at random from 5 to 35 feet from one end of the plat. The borings from each section were composited, giving three composite samples from each plat. The soils were air-dried, mixed thoroughly, and ground for analysis. The organic matter, nitrogen, and phosphorus contents were determined in duplicate on each sample. The results were calculated on a moisture-free basis.

Nitrogen was determined by the Gunning-Hibbard method (1). The inorganic carbon was determined by the Schollenberger (7) method, and the total carbon by the dry combustion method. The organic carbon was obtained by subtracting the values for inorganic carbon from the value for total carbon. The factor 1.724 was used to convert organic carbon to total organic matter. Total phosphorus was determined by the modified magnesium nitrate method (3).

RESULTS

ORGANIC MATTER CHANGES

The data on the organic matter content of the samples taken from the plats in the 2-, 3-, and 5-year rotations are presented in Tables 1, 3, and 4. The tests of significance of the gains or losses during the 20-year period from 1917 through 1937 are also shown in Table 2.

As shown in Table 1, four out of the five plats in the 2-year rotation which did not receive manure lost highly significant amounts of organic matter, whereas only one of the three plats which received manure showed a significant loss. The average loss of organic matter where no manure had been applied was 16.2%.

All the no-treatment plats in the 3-year rotation showed significant losses of organic matter, the average loss amounting to 11.7%; whereas, only one out of seven plats receiving the various treatments showed a significant loss (Table 3).

TABLE 1.—*Changes in contents of organic matter, nitrogen, and phosphorus from 1917 to 1937 in soil of variously treated plats under corn-oats rotation.*

Treatment	Plot No.	Year sampled	Organic matter, %		Nitrogen, %		Phosphorus, %	
			Block II-A	Block II-B	Block II-A	Block II-B	Block II-A	Block II-B
None	805; 810 811; 816	1917 1937	4.26 3.74	3.94 3.14	0.19 0.16	0.18 0.13	0.040 0.038	0.037 0.036
Difference			−0.52†	−0.80†	−0.03†	−0.05†	−0.002	−0.001
Manure and Limestone	806 812	1917 1937	——‡ 3.62	3.84 3.22	——‡ 0.16	0.17 0.14	——‡ 0.039	0.038 0.040
Difference				−0.62†		−0.03†		0.002
Manure, limestone, and rock phosphate	807 813	1917 1937	3.86 3.61	3.33 3.03	0.18 0.17	0.16 0.14	0.042 0.062	0.039 0.051
Difference			−0.25	−0.30	−0.01	−0.02	0.020†	0.012†
Crop residue and limestone	808 814	1917 1937	——‡ 3.89	3.15 2.71	——‡ 0.18	0.15 0.13	——‡ 0.042	0.033 0.036
Difference				−0.44		−0.02		0.003
Crop residue, limestone, and rock phosphate	809 815	1917 1937	4.74 4.01	3.72 3.00	0.22 0.19	0.17 0.14	0.054 0.068	0.042 0.051
Difference			−0.73†	−0.72†	−0.03†	−0.03†	0.014†	0.009†

*Significant.
†Highly significant.
‡No sample available for 1917.

TABLE 2.—*Correlation between original organic matter and nitrogen content of soils and the losses of these constituents, respectively.*

Soil treatment	Soil series	Rotation, years	Degrees of freedom	Correlation coefficients (r)	
				Between original content and loss of organic matter	Between original content and loss of nitrogen
None	Clarion and Webster	2, 3, and 5	6	−0.719*	−0.635
Crop residue, limestone, and rock phosphate	Clarion and Webster	2, 3, and 5	4	−0.924†	−0.921†
All treatments	Webster	5	22	−0.852†	−0.889†
None	Webster	5	5	−0.635	−0.871†

*Significant.
†Highly significant.

All check plats in the 5-year rotation showed significant losses of organic matter, the average loss amounting to 18.2% (Table 4). On the treated plats there was no significant loss except on Webster soils high in organic matter (plats Nos. 930, 931, 1025, 1026, 1030, 1031, 1032, 1033). All the treated Webster soils originally containing more than 7% organic matter showed significant losses.

The average losses of organic matter from the check plats in the various rotations on Clarion soil were as follows: 2-year rotation, 16.1%; 3-year rotation, 11.7%; and the 5-year rotation, 10.2%. The original content of organic matter in the Clarion soils was about 4%. The average loss from the Webster soil on the check plats of the 5-year rotation (plats Nos. 934, 1010, 1012, 1022, 1024, 1034) was about 19%, but the original content was 7.3%.

Correlations between original organic matter content and loss were determined on no-treatment plats and on plats that received crop residue, lime, and rock phosphate, regardless of soil type and rotation. Correlations were also made between original organic matter content and losses on the plats of the 5-year rotation, regardless of soil treatment, and on the no-treatment plats of the 5-year rotation on Webster soil. The data are presented in Table 2. The correlations were found to be significant or highly significant except with the no-treatment plats on Webster soil in the 5-year rotation. The coefficient of correlation of the latter was quite high and probably would have been significant if more samples had been available. These correlations help to show that the larger the amount of organic matter, the larger is the loss. They give the highly significant losses of organic matter which occurred on the Webster soil of the 5-year rotation, regardless of soil treatment, for these plats contain a large amount of organic matter.

NITROGEN CHANGES

The data obtained on nitrogen losses from the plats in three rotations are presented in Tables 1, 3, and 5. The tests of significance of gains or losses are given in Table 2.

TABLE 3.—*Changes in contents of organic matter, nitrogen, and phosphorus from 1917 to 1937 in soil of variously treated plats under corn, oats, and clover rotation.*

Treatment	Plat No.	Year sampled	Organic matter, %			Nitrogen, %			Phosphorus, %		
			Block III-A	Block III-B	Block III-C	Block III-A	Block III-B	Block III-C	Block III-A	Block III-B	Block III-C
None	817; 822 823; 828 829; 834	1917 1937	4.06 3.60	3.69 3.20	6.18 5.51	0.19 0.16	0.17 0.14	0.28 0.25	0.039 0.037	0.037 0.033	0.043 0.046
Difference...........			−0.46†	−0.49†	−0.67†	−0.03†	−0.03†	−0.03†	−0.002	−0.004	0.003
Manure and limestone	818; 824 830	1917 1937	3.58 3.42	4.28 3.44	6.91 6.56	0.18 0.16	0.20 0.17	0.30 0.26	0.035 0.037	0.038 0.036	0.044 0.046
Difference...........			−0.16	−0.84†	−0.35	−0.02*	−0.03†	−0.04	0.002	−0.002	0.002
Manure, limestone, and rock phosphate	819; 825 831	1917 1937	3.68 3.69	—‡ 3.14	—‡ 7.22	0.18 0.17	—‡ 0.15	—‡ 0.29	0.038 0.058	—‡ 0.064	—‡ 0.081
Difference...........			0.01			−0.01			0.020†		
Crop residues and limestone	820; 826; 832	1917 1937	3.89 4.13	—‡ 2.81	—‡ 7.75	0.19 0.18	—‡ 0.14	—‡ 0.33	0.039 0.040	—‡ 0.030	—‡ 0.055
Difference...........			0.24			−0.01			0.001		
Crop residues, limestone, and rock phosphate	821; 827; 833	1917 1937	4.54 4.47	2.78 2.70	—‡ 7.05	0.21 0.20	0.14 0.11	—‡ 0.31	0.041 0.058	0.033 0.054	—‡ 0.075
Difference...........			−0.07	−0.08		−0.01	−0.03†		0.017†	0.021†	

*Significant.
†Highly significant.
‡No sample available for 1917.

Most plats in the 2-year rotation showed significant losses of nitrogen even where treatments of manure or crop residues were made, and all check plats showed significant losses. In the 3-year rotation all check plats showed significant losses, but only three out of seven treated plats showed significant losses.

The check plats in the 5-year rotation showed significant losses of nitrogen in all cases. On treated plats on Clarion soil the losses, in general, were not significant, but on the treated Webster soils high in nitrogen significant losses occurred. The average loss from 10 treated plots on Webster soil containing originally more than 0.3% nitrogen was 18%, whereas the average loss from 12 plats on Clarion soil which received various treatments and contained less than 0.2% nitrogen was 6.4%. Thus, it is evident that the losses of nitrogen are much greater on soils originally containing high amounts of nitrogen. The gains of nitrogen in certain plats of block V-A of the 5-year rotation are probably due to the fact that these plats had been in alfalfa 2 years prior to the sampling of the soil and were in alfalfa when sampled.

The average loss of nitrogen from the check plats of the 2-year rotation on Clarion soil was 21.5%; from those of the 3-year rotation, 13.4%; and from those of the 5-year rotation, 10%. The original nitrogen content was about 0.2% in each rotation. The average loss from the check plats on Webster soil of the 5-year rotation was 18.2% and the average original content was 0.35%.

The correlations between original nitrogen content and loss of nitrogen determined for the same plats as were used in determining the correlation between organic matter content and loss are presented in Table 2. The coefficients of correlation, like those for organic matter, were significant, with one exception, and this one was quite large and probably would have been significant if more samples had been available.

TOTAL PHOSPHORUS CHANGES

The results for total phosphorus and the tests of significance of gains or losses are given in Tables 1, 3, and 6. The losses of total phosphorus, in general, were insignificant, and most of these which were significant were on Webster soil where the original content was high. The gains of total phosphorus were highly significant in every case where rock phosphate was applied, and were significant in a few cases where superphosphate was added. The losses from the soils which received manure alone or manure plus lime were, in general, less than from those receiving crop residues or no treatment. In several cases the plats receiving manure showed slight gains. These apparent slight gains or losses of phosphorus may be misleading since it is certain that the content should be lower after crops have been removed for 20 years. A partial explanation probably lies in the facts that (a) crops take up phosphorus from the subsoil and leave a portion of this in the surface soil as crop residues, and (b) erosion has no doubt removed some surface soil from the plats with the result that some of the layer originally below 6 inches has become incorporated with the plow layer.

TABLE 4.—*Changes in content of organic matter in soils of variously treated plats in a 5-year rotation, 1917–37.*

Treatment	Plat No.	Year sampled	Percentage organic matter†				
			Block V-A	Block V-B	Block V-C	Block V-D	Block V-E
None	912; 917; 922; 924; 929; 934; 1000; 1005; 1010; 1012; 1017; 1022; 1024; 1029; 1034	1917 1937	3.09 2.77	7.32 5.35	5.24 4.68	4.48 4.06	7.34 6.49
Difference..........			−0.32*	−1.97†	−0.56†	−0.42†	−0.85†
Manure	913; 925 1001; 1013; 1025	1917 1937	——‡ 2.96	3.48 3.42	4.51 4.55	3.67 3.51	6.35 5.65
Difference..........				−0.06	0.04	−0.16	−0.70†
Manure and limestone	914; 926 1002; 1014; 1026	1917 1937	2.97 2.63	——‡ 4.31	3.87 4.12	3.67 3.30	7.21 6.58
Difference..........			−0.34		0.25	−0.37	−0.63†
Manure, limestone, and and rock phosphate	915; 927 1003; 1015; 1027	1917 1937	——‡ 2.73	5.83 5.49	3.83 3.89	3.88 3.65	6.33 6.51
Difference..........				−0.34	0.06	−0.23	0.18

Manure, limestone, and superphosphate	916; 928 1004; 1016; 1028	1917 1937	3.21 3.16	6.51 6.05	4.51 4.48	4.52 4.32	—‡ 6.20
Difference..........			−0.05	−0.46	−0.03	−0.20	
Crop residue	918; 930 1006; 1018; 1030	1917 1937	3.81 3.66	8.06 7.09	4.77 4.70	3.33 3.42	9.39 7.33
Difference..........			−0.15	−0.97†	−0.07	0.09	−2.06†
Crop residue and limestone	919; 931 1007; 1019; 1031	1917 1937	3.84 3.53	7.54 6.82	4.92 4.79	3.73 3.55	9.96 8.10
Difference..........			−0.31	−0.72†	−0.13	−0.18	−1.86†
Crop residue, limestone, and rock phosphate	920; 932 1008; 1020; 1032	1917 1937	3.65 3.48	6.66 6.24	—‡ 5.43	4.67 4.41	10.18 8.70
Difference..........			−0.17	−0.42		−0.26	−1.48†
Crop residue, limestone, and superphosphate	921; 933 1009; 1021; 1033	1917 1937	3.66 3.37	6.75 6.51	5.85 5.61	5.34 5.03	10.85 8.60
Difference..........			−0.29	−0.24	−0.24	−0.31	−2.25†

*Significant.
†Block A was in alfalfa, 1935–37; B, 1930–34; C, 1915–19; D, 1920–24; E, 1925–29. Highly significant.
‡No sample available for 1917.

TABLE 5.—*Changes in nitrogen content of soils of variously treated plats in a 5-year rotation, 1917–37.*

Treatment	Plat No.	Year sampled	Percentage nitrogen				
			Block V-A	Block V-B	Block V-C	Block V-D	Block V-E
None	912; 917; 922; 924; 929; 934 1000; 1005; 1010; 1012; 1017; 1022; 1024 1029; 1034	1917 1937	0.16 0.14	0.33 0.25	0.23 0.21	0.21 0.19	0.36 0.32
Difference..........			−0.02*	−0.08†	−0.02*	−0.02*	−0.04†
Manure	913; 925 1001; 1013; 1025	1917 1937	—† 0.15	0.17 0.16	0.22 0.20	0.16 0.17	0.29 0.25
Difference..........				−0.01	−0.02*	0.01	−0.04†
Manure and limestone	914; 926 1002; 1014; 1026	1917 1937	0.13 0.14	—† 0.19	0.18 0.19	0.17 0.16	0.32 0.27
Difference..........			0.01		0.01	−0.01	−0.05†
Manure, limestone, and rock phosphate	915; 927; 1003 1015; 1027	1917 1937	—† 0.14	0.26 0.24	0.19 0.19	0.17 0.17	0.29 0.28
Difference..........				−0.02*	0.00	0.00	−0.01

Manure, limestone, and superphosphate	916; 928; 1004 1016; 1028	1917 1937	0.16 0.16	0.30 0.26	0.23 0.20	0.21 0.21	—† 0.29
Difference..........			0.00	−0.04†	−0.03†	0.00	
Crop residue	918; 930 1006; 1018; 1030	1917 1937	0.17 0.18	0.37 0.31	0.22 0.21	0.19 0.15	0.50 0.36
Difference..........			0.01	−0.06†	−0.01	−0.04†	−0.14†
Crop residue and limestone	919; 931; 1007 1019; 1031	1917 1937	0.16 0.17	0.38 0.31	0.22 0.21	0.21 0.16	0.51 0.39
Difference..........			0.01	−0.07†	−0.01	−0.05†	−0.12†
Crop residue, limestone, and rock phosphate	920; 932 1008; 1020; 1032	1917 1937	0.17 0.17	0.31 0.29	—† 0.24	0.21 0.20	0.50 0.40
Difference..........			0.00	−0.02*		−0.01	−0.10†
Crop residue, limestone, and superphosphate	921; 933 1009; 1021; 1033	1917 1937	0.17 0.16	0.32 0.27	0.24 0.24	0.24 0.21	0.52 0.40
Difference..........			−0.01	−0.05†	0.00	−0.03†	−0.12†

*Significant.
†Highly significant.
‡No sample available for 1917.

TABLE 6.—*Changes in phosphorus content of soils of variously treated plats in a 5-year rotation, 1917–37.*

Treatment	Plat No.	Year sample	Percentage phosphorus				
			Block V-A	Block V-B	Block V-C	Block V-D	Block V-E
None	912; 917; 922; 924; 929; 934 1000; 1005; 1010; 1012; 1017; 1022; 1024; 1029; 1034	1917 1937	0.032 0.032	0.045 0.041	0.041 0.038	0.039 0.036	0.069 0.057
Difference..........			0.000	−0.004*	−0.003	−0.003	−0.012†
Manure	913; 925; 1001 1013; 1025	1917 1937	——‡ 0.035	0.032 0.035	0.038 0.039	0.035 0.035	0.047 0.040
Difference..........				0.003	0.001	0.000	−0.007*
Manure and limestone	914; 926; 1002 1014; 1026	1917 1937	0.030 0.033	——‡ 0.036	0.034 0.037	0.036 0.036	0.056 0.042
Difference..........			0.003		0.003	0.000	−0.014†
Manure, limestone, and rock phosphate	915; 927; 1003 1015; 1027	1917 1937	——‡ 0.055	0.043 0.084	0.039 0.063	0.051 0.064	0.064 0.088
Difference..........				0.041†	0.024†	0.013†	0.024†

Manure, limestone, and superphosphate	916; 928; 1004	1917	0.032	0.043	0.037	0.043	——‡
	1016; 1028	1937	0.039	0.047	0.044	0.044	0.055
Difference..........			0.007*	0.004	0.007*	0.001	
Crop residue	918; 930; 1006	1917	0.034	0.051	0.038	0.033	0.060
	1018; 1030	1937	0.034	0.047	0.037	0.031	0.062
Difference..........			0.000	−0.004	−0.001	−0.002	0.002
Crop residue and limestone	919; 931; 1007	1917	0.037	0.053	0.042	0.035	0.088
	1019; 1031	1937	0.035	0.051	0.037	0.034	0.075
Difference..........			−0.002	−0.002	−0.005	−0.001	−0.013
Crop residue, limestone, and rock phosphate	920; 932; 1008	1917	0.038	0.054	——‡	0.049	0.113
	1020; 1032	1937	0.050	0.090	0.068	0.058	0.130
Difference..........			0.012†	0.036†		0.009†	0.017†
Crop residue, limestone, and superphosphate	921; 933; 1009	1917	0.035	0.045	0.040	0.043	0.095
	1021; 1033	1937	0.037	0.099	0.045	0.042	0.091
Difference..........			0.002	0.054†	0.005	−0.001	−0.004

*Significant.
†Highly significant.
‡No sample available for 1917.

SUMMARY

A composite sample of soil was taken from each plat of the 2-, 3-, and 5-year rotation experiments involving various manurial treatments at the Agronomy Farm of the Iowa Agricultural Experiment Station in 1917. These plats were sampled again in 1937, taking three composite samples from each plat. The samples taken in 1917 and those taken in 1937 were analyzed in 1937 for organic matter, nitrogen, and total phosphorus.

A statistical analysis was made to test the significance of the gains or losses of organic matter, nitrogen, and phosphorus of each plat of the three rotations. Correlations between original organic matter and nitrogen contents and the losses of these constituents were determined.

The data available were not sufficient to make as many tests as desired. Nevertheless, the following conclusions are believed warranted:

1. The losses of organic matter and nitrogen were less with the 3- and 5-year rotations than with the 2-year rotation. The average loss of organic matter on Clarion loam where manure was not applied was 16.2% with the 2-year rotation, 11.7% with the 3-year rotation, and 10.2% with the 5-year rotation. On the Webster silt loam there was a loss of 19% with the 5-year rotation.

2. The loss of nitrogen in the Clarion loam, average of all checks, was 21.5% with the 2-year rotation; 13.4% with the 3-year rotation; and 10.0% with the 5-year rotation. In the Webster silt loam the loss was 18.2% with the 5-year rotation.

3. The decreases in organic matter and nitrogen where manure was applied were much less than where crop residues were returned.

4. In general, the losses of total phosphorus were insignificant. The losses from soils treated with manure alone or manure and lime were generally less than from the check plats or the plats treated with crop residues. The soils treated with rock phosphate showed highly significant gains in phosphorus. The losses of phosphorus from the untreated soils were less than the amounts of phosphorus removed in the crops during the period of the experiment, indicating an accumulation of phosphorus in the surface soil from the residues returned.

5. In most cases there were found to be highly significant correlations between original organic matter and nitrogen contents and the losses of these constituents. The larger the original contents, the larger were the losses.

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THE USE OF FORAGE-ACRE REQUIREMENTS IN RANGE SURVEYS[1]

R. R. Humphrey[2]

REGARDLESS of the detail involved in taking inventory of the grazing resources of a range, or of the accuracy of the work, the data obtained have only limited value without a knowledge of the number of forage acres required to graze an animal unit for a given period.[3] Such an inventory, or range survey, tabulates its findings in forage acres of feed available. The forage-acre requirement, here also referred to in abbreviated form as F.A.R., provides a measuring stick for adjusting the number of animals to the forage resources of the range as determined by the survey.

Forage acres of available feed cannot readily be converted into grazing capacities without employing forage-acre requirement figures. Furthermore, such conversions cannot be made correctly without the proper forage-acre requirements. It is evident, therefore, that F.A.R. studies should be conducted with great care and accuracy.

Range surveys have been made in the past on areas for which no forage-acre requirement figures were available. In certain of these cases, a tentative rate of stocking was proposed that was later modified as subsequent improvement or deterioration of the range required. Such a method of attempting to apply the results of a forage survey is little better than proceeding without any survey data.

A second method of limited applicability, that has been used in many instances in the absence of a forage-acre requirement figure, might be called the direct stocking method. This involves obtaining grazing capacity figures on a pasture of known area that appears to have been properly stocked, and applying this same rate of stocking to other essentially similar areas. The disadvantage of this method, as compared with use of a definite forage-acre requirement, is that no inventory of the forage is taken and, consequently, the rate of stocking determined can be applied only to areas that seem to have about the same grazing capacity.

A forage-acre requirement, on the other hand, can be applied over a much wider range of conditions, its applicability not being limited

[1]Contribution from the Soil Conservation Service, U. S. Dept. of Agriculture, Spokane, Wash. Received for publication July 1, 1940.

[2]Associate Range Examiner, Pacific Northwest Region, Soil Conservation Service. The writer wishes to express appreciation to his many associates who, through their discussion and constructive criticism, have assisted in developing the ideas here set forth.

[3]Definitions used by the U. S. Soil Conservation Service:

Forage Acre: Range land in the amount necessary to furnish the equivalent of 1 acre completely (10/10) covered with vegetation that is 100% palatable. The number of forage acres in a type is obtained by multiplying the number of surface acres by the forage factor.

Forage factor: The figure arrived at by multiplying the palatability of a type by the average density.

Forage-acre requirement: The number of forage acres necessary to support and maintain an animal for a definite period of time.

by amount of available forage. The F.A.R. method, therefore, is relatively flexible and has a broad application as contrasted with the direct stocking method.

As long as the type and amount of forage remains the same, year after year, the forage-acre requirement will not vary appreciably on a given area, although it may vary widely from one locality to another, even on adjacent areas. For example, a forage acre on a grass range may not, and probably will not, have the same feeding value as a forage acre on a browse range. This fact often makes it difficult to employ fixed forage-acre requirement figures over legally delineated areas (sections or townships).

In surveying areas to determine forage-acre requirements, only perennials usually are included in the forage inventory. Annuals can be included in certain instances, but because of their ephemeral character and the difficulty of estimating correctly densities and composition, their inclusion in the estimates may be accompanied by a degree of error greater than would obtain were they omitted. Regardless of whether or not annuals are included, the degree of grazing they are permitted to receive will depend on the type of vegetation that should be maintained on the area. For example, on ranges where annual species have invaded as a result of improper management, and where perennials should be restored, use of the annuals should be sufficiently light not to interfere with the desired revegetation. On range lands of the type often encountered in Arizona and New Mexico, on the other hand, where annuals may comprise a natural seasonal phase of the vegetation even under proper utilization, the degree of grazing pressure allowed may be based on perpetuation of annual rather than perennial species.

When annuals are not included in the grazing surveys made on the areas to which the forage-acre requirement is to be applied, they likewise must be omitted in determining the forage-acre requirement. To do otherwise would not only be a waste of time; it would give erroneous results indicating a higher grazing capacity than actually obtained on the area to which the forage-acre requirement was to be applied.

Similarly, it is not always necessary to consider volume growth of grasses or other vegetation in making either range surveys or F.A.R. studies. It will be noted that this touches on a point that is much discussed in connection with range surveys, namely, the allowance that should be made to provide for volume growth. It is true that the volume may not be constant, even on the same area in different years. This factor will be of little consequence, however, provided the volume growth on the area to which the forage-acre requirement is to be applied is evaluated in relation to the probable average volume growth over a period of years, which, of course, presupposes that the F.A.R. study is based on information that permits a correct evaluation of average volume production for that particular type.

The term forage-acre requirement has been objected to on the ground that an animal will require as many forage acres on one type of range as on another. The suggestion has been made, therefore, that the word "requirement" should be replaced by "allowance"

in all references to the number of forage acres needed to support a given animal for a given length of time. The basis for this suggestion seems to lie largely in the opinion that any one forage acre is the equivalent of any other forage acre in feeding value.

The fallacy of this reasoning is readily apparent when we consider such contrasting types of forage as annual weeds and perennial grasses. Such entirely dissimilar types of forage should no more be expected to have the same calorific value than would a pound of lettuce and a pound of beefsteak. Similarly, in view of the fact that volume growth generally does not enter into grazing capacity determinations until after the F.A.R. has been applied, it would obviously be incorrect to assign the same forage-acre requirement to blue grama or other short-grass range as to one supporting wheatgrass or a similar type of vegetation.

It is true, that, in some instances, different forage-acre requirements should be set up, not on a basis of different feeding values in a given unit of forage, but on a basis of forage potential, slope, or other factors. In such cases, it might be more nearly correct to apply the term forage-acre allowance than forage-acre requirement. Even so, as "requirement" is in common use today and because this use is technically correct in many instances, it would seem that the term should continue to be used in this way.

Vegetation, soil, slope, and climate must be the principal criteria employed in determining the areas to which certain forage-acre requirements are to be applied. However, as vegetation is the product, in large part, of soils and climate, it is often possible to determine the area of application of a given forage-acre requirement largely on a basis of vegetation. Additional factors, somewhat different in nature, are sometimes involved, requiring use of separate F.A.R. figures. The principal factors that necessitate the use of more than one forage-acre requirement are, essentially, the following:

1. *Amount of unmeasured forage present.*—This may result from growth of annuals, a longer than average growing season, recurrent growth on perennials, or volume growth. The greater the amount of unmeasured forage present, the lower the forage-acre requirement. The effect of annuals is particularly evident in the brushy desert ranges of the Southwest, where the so-called "winter and summer annuals" provide large amounts of feed for short periods.

2. *Differences in nutrient value of different types of forage.*—Differences in nutrient value may be the result of several factors, one of the more important of which is soil. Insofar as dissimilar soils produce different kinds of vegetation varying in nutrient values and these differences can be determined, unlike soils may require different forage-acre requirements.

3. *Condition of range.*—As forage-acre requirement figures are based on ranges managed on a sustained-yield basis, deteriorated areas will require higher forage-acre requirements to allow for recovery. Wherever possible, of course, F.A.R. determinations should be made on properly grazed ranges. In some instances, however, such areas are not available. A forage-acre requirement obtained on deteriorated rangelands, if applied without modification to similar

areas, presumably will tend to maintain those ranges at their deteriorated level. Therefore, if the vegetation and grazing capacity of these lands is to be restored to the former level, application of a somewhat higher F.A.R. than was actually obtained in the study will be necessary. This item, on the other hand, may be handled for individual types or for the range as a whole, by applying a cut to the gross animal months of forage instead of by an increase in the forage-acre requirement.

4. *Variations in density and composition estimates made by different survey parties.*—Inasmuch as grazing surveys are based in large part on estimates, and as no absolute standard is available with which to check these estimates, different survey parties may vary the number of forage acres on a given area. For this reason it is essential that each survey party either work out its own forage-acre requirements, or correlate its survey with those of the other agencies involved. This correlation should be made with sufficient care to make it possible to determine the modification of one agency's forage-acre requirement necessary to permit its application to survey data obtained by the alternate agency.

5. *Differences in elevation, exposure, and precipitation.*—Differences in vegetation that normally occur at different elevations or exposures often are largely the result of variations either in the moisture balance or in the total precipitation falling on the area. Where such vegetal variations occur, a change in the forage-acre requirement will usually be necessary.

6. *Differences in slope.*—Steep slopes, in general, are more erodible than gentle ones and, because they are also usually less accessible, are less heavily grazed. The difference in permissible grazing use is usually handled on small areas by assigning a cut to the steeper slopes; but where this has not been done, or on ranges which, because of slopes, are markedly more erodible than others, a higher F.A.R. should be employed than would be used on more nearly level range.

7. *Variations in forage-production potentials of different soils.*—Certain soils may produce a greater volume of forage and consequently should have a lower forage-acre requirement than other poorer soils that may be immediately adjacent. This item, like items 3 and 6, can be handled by applying a cut to the gross animal months of forage rather than by an increase in the forage-acre requirement.

8. *Erodibility of soils.*—Ranges with highly erodible soils will generally need a higher forage-acre requirement than those where soils are less likely to erode. However, where variations in erodibility of soils are caused by differences in degree of slope rather than by variations in soils, and where closeness of grazing is controlled by regulation of the number of forage acres allowed an animal unit on the area, there usually will be no correlation between forage-acre requirement and soil type, but rather between forage-acre requirement and slope. Occasionally, there may be a general correlation to broad soil types, but not to narrow ones.

9. *Grazing practices.*—Range utilized on a deferred or rotation grazing system usually will provide more forage than similar areas

that receive continuous use, and consequently should have a lower forage-acre requirement.

10. *Uniformity of forage utilization.*—On range with rough topography, inadequate water, or other local conditions preventing uniform utilization of all the forage, it may be necessary to use a higher forage-acre requirement than on otherwise similar, but more uniformly utilized range. A condition of this sort, however, can be, and usually is handled by assigning a cut to the gross forage acres.

The essential factors to be considered in making forage-acre requirement studies in the field are presented in the following outline:[4]

I. Selection of areas.
   A. The area studied should be typical of the area to which the forage-acre requirement will be applied as to type of vegetation, topography, and soil, and should be grazed by the same class of stock. Wherever possible the entire ranch, rather than a single pasture, should be used.
   B. Preferably the pasture should be in good condition.
      1. The examiner will be guided by the following indicators of good condition:
         a. Good density and vigorous condition of the desirable forage species. Condition judged by color, general appearance, and height of growth.
         b. Absence of accelerated soil erosion.
         c. Absence of extensive areas overrun by annual weeds and grasses or by other plants indicating vegetational deterioration.
         d. Lack of evidence of local overgrazing resulting from poor distribution of water and salt or other factors.
      2. In an area where it is not possible to locate a suitable pasture in good condition because of overgrazing, drought, rodent damage, or poor management, the examiner in the field must appraise the cause, nature, and extent of the unsatisfactory condition in order to make adjustments required to place the study on a satisfactory basis. On overgrazed ranges, the examiner must judge the extent of overgrazing. Factors that appear trivial may aid in evaluating the condition of the range and have a bearing on the F.A.R.
   C. The pasture should be of sufficient size to constitute a reliable sample of the area. The most satisfactory size of pastures on which dependable data can be assembled is probably between 640 and 5,000 acres.
   D. The pasture should be fenced in order to control numbers of livestock and thus eliminate influences that might affect the reliability of the resulting data and conclusions.

[4]Adapted in part from Instructions for Collection of F.A.R. Data on Selected Pastures (manuscript), by L. R. Albee, Soil Conservation Service, Ft. Meade, South Dakota.

II. Records of actual stocking.

A. The examiner should select a pasture for study on which actual stocking records have been kept for a number of years.

1. Records kept for 10 years or longer are best, yet most consideration should be given to significant trends of recent years.
2. Four years of reliable records should be considered the acceptable minimum.
3. Written records are most desirable, but in the absence of these, good memory records can be used.

B. The records should include the following data:

1. Number of head of each class and age of livestock grazed on the unit (horses, cows, yearling steers, and sheep). This information is essential in converting the livestock to a common unit.
2. Length of the grazing period each year.
   a. Date that stock were put on pasture.
   b. Date of removal.
3. Reasons for variations in number of animal units grazed, or in length of grazing period when the departure from the average is significant.
   a. The most desirable stocking records are those having the least yearly departure from the average over a period of years, because such a record will generally indicate that the stockman, to some extent, has systematized his grazing operations.
   b. During seasons of general drought or some unfavorable economic condition, the exact circumstances that caused any significant departure should be ascertained. This is an important item about which the examiner should obtain all the information possible.
4. Amount of supplementary feed supplied.
   Where supplementary feed has been furnished, the feeding value of this feed should be taken into consideration in determining the dependence of the animals on the range forage.

In collecting forage-acre requirement data, the information given below should be the minimum obtained: (1) Forage resources of area, expressed in forage crops; (2) stocking records of area, converted to animal units; and (3) supplementary feed furnished during grazing season.

The following equation may be useful in calculating forage-acre requirements: Assuming availability of a 5-year stocking record, the average monthly use over this period should be obtained, $\frac{A}{B} = C$, where A = number of forage acres; B = cow months of use; and C = monthly forage-acre requirement. In obtaining B, the animal months of supplementary feed furnished should be subtracted from the total

animal months of feed obtained from both grazing and feeding before calculating the forage-acre requirement.[5]

An example of the data obtained may be summarized and calculated as follows:

20 cows	@ 1.0	Animal Units	=	20.00	Cow Units	
1 bull	@ 1.25	" "	=	1.25	" "	
10 yearlings	@ .75	" "	=	7.50	" "	
10 calves	@ .6	" "	=	6.00	" "	
50 mixed	@ .8	" "	=	40.00	" "	
3 horses	@ 1.25	" "	=	3.75	" "	
3 mares	@ 1.25	" "	=	3.75	" "	
Total......................				82.25	Cow Units	

82.25 cow units $\times$ length of time grazed (assume 7 months) = 576 cow months use. Postulating 119 forage acres of feed available:

$$\frac{\text{119 forage acres}}{\text{576 cow-months use}} = 0.2 \text{ forage acres required per cow month, i.e.,}$$

a monthly forage-acre requirement of 0.2.

[5]A breeding cow is considered as one animal unit and values are assigned to all other ages and classes of livestock based on estimates of the relative amounts of forage consumed by them.

EFFECT OF LEVEL TERRACES ON YIELD AND QUALITY OF PASTURAGE AND WATER CONSERVATION[1]

H. R. BENFORD AND D. G. STURKIE[2]

THE amount and distribution of rainfall are important factors influencing the amount and seasonal distribution of pasture growth. This is especially true on upland sandy soils of the South where runoff and percolation are sometimes so rapid that moisture becomes a limiting factor in pasture growth even during relatively short periods of drouth. Mayton (3)[3] found that the average seasonal yield of pasturage was associated very closely with the average distribution of rainfall with an approximate 20-day time lag.

Studies by Greene (1), using closely-spaced terraces, 40 inches apart, showed that level terracing was effective in preventing all runoff for the season except for excessive rains which overflowed the terraces. According to his observations, more forage was produced per acre where level terraces were used and cattle preferred the pasturage on the terraced area to that on the unterraced.

Since moisture is often a limiting factor in pasture production on upland soils in the South, it is desirable to know some practical means of conserving moisture and thus increasing production. The experiment herein reported was therefore conducted to determine the effect of level terraces on water conservation and on yield and production of pastures. These studies were made at the Alabama Agricultural Experiment Station, Auburn, Alabama.

EXPERIMENTAL

An area of Norfolk sandy soil with a slope of 15 to 20% was selected. This area had been in pasture for several years but was supplying very little grazing because of its low fertility (Fig. 1). By making a small drain down the slope the pasture was divided into two approximately equal areas. One area was level terraced and the other was left unterraced (Fig. 2). On the terraced area about twice the number of terraces was built that would have ordinarily been used for cultivated fields (Fig. 3). These terraces were of the Nichols (2) type with a base of from 16 to 20 feet and a depth of about 18 inches in the center of the channel. One end of each terrace was closed and the other end was so constructed that after the channel was filled, the excess water drained into a cistern where it was measured. Each terrace had a holding capacity of about 6 cubic feet of water per linear foot, making it possible to hold about a 2-inch rainfall on the area.

The terraced area was prepared for seeding by breaking to a depth of about 4 to 6 inches. It was then subsoiled to a depth of about 14 inches between terraces to increase the absorption of water. The unterraced area was prepared by breaking to a depth of 4 to 6 inches and was not subsoiled.

[1]Contribution from the Department of Agronomy and Soils, Alabama Agricultural Experiment Station, Auburn, Ala. Authorized for publication by the Director. The cooperation and suggestions of the Department of Agricultural Engineering, especially of Professor M. L. Nichols, for designing and supervising the construction of the terraces, are gratefully acknowledged. Received for publication July 17, 1940.

[2]Graduate Assistant and Associate Agronomist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 767.

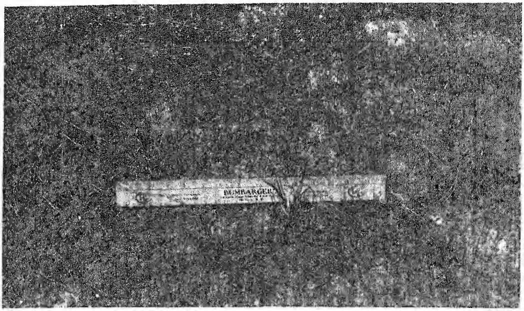

FIG. 1.—View showing condition of sod on untreated area. Compare with Fig. 4.

On March 4, 1935, basic slag (8% P_2O_5) was broadcast over both areas at a rate of 1 ton per acre and disked in thoroughly. On March 16, 1935, the entire pasture was seeded to a mixture of Dallis grass (*Paspalum dilatatum*), 19 pounds per acre; common lespedza (*Lespedza striata*), 17 pounds per acre; Kentucky bluegrass (*Poa pratensis*), 22 pounds per acre; and hop clover (half *Trifolium dubium* and half *Trifolium procumbens*), 2 pounds per acre. The seed were sown broadcast and then covered with a section harrow. By April 16, 1935, there was a good stand of all plants seeded. At this time an application of 100 pounds per acre of nitrate of soda was broadcast uniformly over each area.

An application of superphosphate (16% P_2O_5), broadcast on both areas at a rate of 400 pounds per acre on September 17, 1938, was followed on October 17, 1938, by a seeding of lappa clover (*Trifolium lappaceum*), 2 pounds per acre, and white clover (*Trifolium repens*), 3 pounds per acre.

Records were taken throughout 1938 and 1939 during which time the flora in the spring was largely hop clover with some white clover and Kentucky bluegrass, and in the summer was Dallis grass and common lespedeza. The pasture was

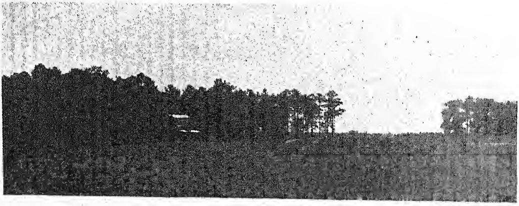

FIG. 2.—General view of pasture showing terraced area (left) and unterraced area (right), placement of cages, drain separating the two areas, and erosion on the lower side of the unterraced area.

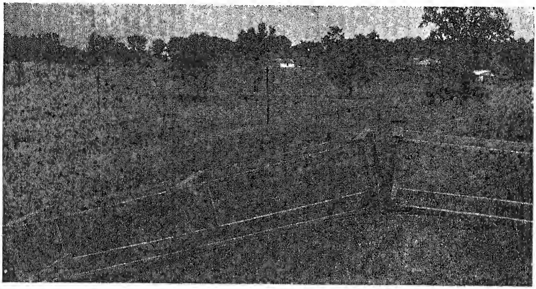

FIG. 3.—View of terraced area showing cages, terraces, and bare strip along the top of terraces.

grazed with cattle continuously throughout the study, and also mowed at intervals for weed control. Observations were made concerning the general condition of each area as to weeds and erosion.

To determine the yield and quality of pasturage, wire cages were distributed systematically over both terraced and unterraced areas. All cages were 3 feet by 18 feet and were constructed with a hinge on the base rails so that they could be placed across terraces (Fig. 3). Plant material was cut with a lawn mower when the plants under the cages reached a height of 4 to 5 inches. The green material was weighed immediately, and a ½-pound sample saved for analysis. The pastur-

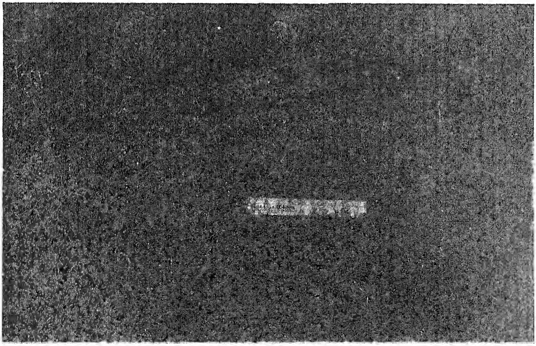

FIG. 4.—View showing grazed and ungrazed areas. *Left*, ungrazed; *right*, grazed. Compare with Fig. 1.

age on an area of equal size just outside each cage was cut, the material weighed, and its weight subtracted from the weight of that under the cage in order to determine the amount consumed by livestock (Fig. 4). After each cutting the cages were moved to new places. Samples that were saved for analysis were oven-dried (100° F) and determinations were made of dry matter and total nitrogen.

To determine the influence of level terraces on water conservation, measurements of runoff from both terraced and unterraced areas were recorded by Stevens water level recorders which were placed in cisterns.

RESULTS AND DISCUSSION

A good stand of plants was present on both the terraced and unterraced areas throughout the test. The rainfall was normal in April, July, and September; below normal in May and June; and above normal in August. Thus an excellent opportunity was afforded to study the effectiveness of moisture conservation. From Table 2 it may be seen that a period of high rainfall in April was followed by one of low rainfall in May and June and one of high rainfall in August by one of low rainfall in September.

YIELD AND SEASONAL GROWTH

The data in Table 1 show that there was practically no difference in the total yield of dry matter produced per acre under terraced and unterraced conditions.

PERCENTAGE OF DRY MATTER AND PROTEIN

There was little difference in the average percentage of dry matter produced on the terraced and unterraced areas (Table 1). During dry seasons, however, there was some tendency for the moisture content of plants to be higher on the terraced than on the unterraced area. This was probably caused by the high moisture content of plants growing in the terrace channel, which in many cases were undesirable weeds rather than edible plants.

There was little difference in the average protein content of the dry matter from the terraced and unterraced areas.

PERCENTAGE DRY MATTER CONSUMED

Data in Table 1 show that for the season as a whole there was little difference in percentage dry matter consumed from the two areas. The larger percentage consumed in April from the unterraced area was probably caused by the presence of a higher percentage of hop clover on the unterraced area than on the terraced area, and to the fact that there was little grazing above terraces during this month because of surface water immediately above terraces and settlings on plants after the water had evaporated or had percolated into the soil. Except for the early spring period, percentage consumption seemed to vary inversely with yields under both terraced and unterraced conditions. During June, July, and September more material was consumed than was produced which means that part of the pasturage consumed during these months grew previously. The surplus production of high-producing periods was utilized during low-producing periods (Fig. 5).

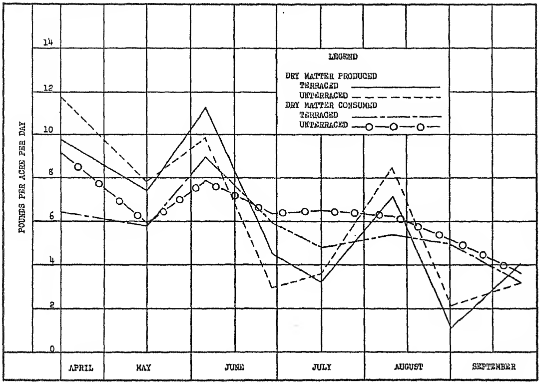

FIG. 5.—Average daily acre yields of dry matter and average daily acre consumption of dry matter from terraced and unterraced conditions, 1938–39.

TABLE 1.—*Influence of level terraces on yield of dry matter, protein content, dry matter consumed, and seasonal growth of pasturage, 2-year average, 1938–39.*

Approximate cutting dates	Pounds of dry matter harvested per acre		Percentage dry matter		Percentage protein		Percentage dry matter consumed*	
	Terraced	Unterraced	Terraced	Unterraced	Terraced	Unterraced	Terraced	Unterraced
Apr. 15....	295	355	29.4	29.2	15.6	17.6	66.1	77.5
May 15....	227	237	27.3	31.0	15.0	15.2	76.7	75.6
June 5.....	248	217	25.3	30.1	12.9	12.9	75.8	76.5
June 28....	100	65	32.9	37.4	12.0	12.3	139.0	226.2
July 15.....	55	62	34.6	35.6	12.7	11.3	149.0	180.6
Aug. 10....	186	221	24.4	23.7	13.4	12.7	75.3	74.7
Sept. 1.....	25	49	28.4	32.5	16.0	12.2	444.0	234.7
Sept. 25....	98	76	41.9	38.8	12.2	13.2	77.6	110.5
Total....	1,234	1,282	—	—	—	—	—	—
Average	—	—	28.3	29.6	13.9	14.4	89.5	92.9

*Percentage based on amount produced during the period under consideration.

WATER CONSERVATION

Data in Table 2 show the amount of water conserved by level terraces during the growing season of 1939. Pasture plants require from

425 to 550 pounds of water to produce 1 pound of dry matter (4, 5). Using 500 pounds of water as the amount required to produce a pound of dry matter, the terraced area should have produced 633 pounds above that produced by the unterraced area if all the water conserved had been utilized (Table 2).

TABLE 2.—*Rainfall and water losses by months during the growing season under terraced and unterraced conditions, 1939.**

Month	Rainfall		Water lost by runoff, pounds per acre		Pounds of water conserved per acre by level terraces	Theoretical increase possible in yield per acre from terracing, pounds†
	Inches	Pounds per acre	Terraced	Unterraced		
April.....	4.08	924,169	41,159	216,154	174,995	350
May......	3.73	844,890	4,368	19,406	15,038	31
June......	2.35	532,303	7,301	27,643	20,342	41
July......	3.53	799,587	3,609	14,664	11,055	22
August....	9.63	2,181,311	264,701	353,246	88,545	177
September	4.00	906,048	12,667	18,782	6,115	12
Total...	27.32	6,188,308	333,805	649,895	316,090	633

*1938 results were not used because cisterns were out of order.
†This figure was determined by dividing the pounds of water conserved by 500. Five hundred pounds of water is the approximate amount required to produce a pound of dry matter.

Even though considerable water (about 50% of runoff) was conserved by level terraces, there was no increase in yield. This lack of increased yield under terraced conditions seemed to be due to three conditions. First, the water was conserved at a time when it was plentiful, at which time it was lost by evaporation from the surface and by percolation into the soil below the root zone where it was not available when needed by plants. Second, the water accumulated in a small area just above the terraces and had a tendency to silt and drown out pasture plants. Third, the tops of the terraces were subject to drouth, causing 2- to 3-foot bare strips along the tops of the terraces, as illustrated in Fig. 3.

These results indicate that there was little advantage in attempting to conserve moisture in humid climates by means of level terraces on upland sandy soils for the growth of shallow-rooted pasture plants. It seems, therefore, that the most logical solution would be to locate deep-rooted plants capable of growing on these soils.

GENERAL OBSERVATIONS

Weeds were more prevalent on the terraced area than on the unterraced area. The moisture conditions in the terrace channel probably accounted for the weed growth which crowded out the desirable pasture plants. Weeds on the terraced area were more difficult to control than on the unterraced area because of the difficulty of mowing over the terraces.

The indications were that the unterraced area will be seriously eroded in a few years if left unterraced, while no apparent erosion

was evident on the terraced area (Fig. 2). Although terracing did not increase production in this experiment, upland permanent pastures should be sufficiently terraced to prevent erosion.

SUMMARY

Results are reported of studies on the effect of level terraces, 16 to 20 feet wide at the base and spaced twice as close as ordinarily used, on yield and quality of pasturage and runoff from an upland Norfolk sandy soil of low fertility and 15 to 20% slope at Auburn, Alabama, during the 2-year period, 1938–39, inclusive.

The terraces reduced the runoff approximately 50% but were not effective in increasing pasture yields. They had little effect on percentage dry matter and percentage protein in the plants.

There was no decided difference in the percentage of dry matter consumed under terraced and unterraced conditions. Percentage consumption varied inversely with yields, indicating that the consumption curve may be smoothed out for the entire grazing season by properly stocking the pasture.

There were more weeds on the terraced area than on the unterraced area. Weed growth was luxuriant along the terrace channel.

Considerable erosion was noticeable on the unterraced area, indicating the need for terracing to control erosion. No appreciable erosion occurred on the terraced area.

On the basis of the results obtained in this study, it may be concluded that level terraces were not effective in increasing the pasturage on Norfolk sandy soil; however, the terraces were desirable for soil conservation.

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DISEASE INFECTION AND FIELD PERFORMANCE OF BIN- AND HANGER-DRIED SEED CORN[1]

BENJAMIN KOEHLER AND GEORGE H. DUNGAN[2]

ONE of the changes in the preparation of seed corn that took place on a wide scale when the production of hybrid seed corn developed as a specialized business, was the employment of hot-air-drying bins in place of ear-corn hangers for drying the seed. This change has resulted in a considerable economy of space and labor. The investigation herein reported was intended to determine whether this change has also resulted in an improvement in the quality of the seed. Two independent sets of experiments were conducted.

EARS BIN-DRIED BY PRODUCERS

At seed-corn harvesting time in 1936, 1937, and 1938, 20-ear samples of a number of different hybrids and varieties were collected from several producers and dried in Martin hangers located on the third floor of the Agronomy Building, University of Illinois South Farm, Urbana, Ill. Two such hangers are shown in the chamber in Fig. 2. Adequate ventilation was provided to facilitate the drying of the ears, and steam heat was supplied on very cold days. Conditions during the entire period of storage were believed to be favorable for seed corn. Seed cured and stored in this manner has been designated in this report as "hanger-dried" corn.

Seed of the same hybrids and varieties which had been cured in heated bins in the usual way and had been shelled, graded, and treated for disease control was furnished the next spring by the producers. The grade "medium flat" was used. This seed has been designated as "bin-dried" corn. Part of a small commercial processing plant is shown in Fig. 1.

Field tests of the performance of the two lots of seed corn from the respective collections were made in 1937, 1938, and 1939, on the Agronomy South Farm. Plots were 10 hills long and two rows wide. Ten plots of each entry were planted each year. The hanger-dried seed was treated with a fungicide to correspond with that used by the commercial producers. The hanger-dried corn was planted adjoining the bin-dried corn in all cases, so the trials may be said to be paired experiments. Three kernels were planted by hand in each hill. The field stand represents the percentage of kernels planted that produced plants in the field.

The results of the three years' test involving 19 different kinds of corn and 12 different bin driers show (Table 1) that the hanger-dried corn produced an average field stand of 93.9% compared with 92.1% for the bin-dried corn. In yield of grain the hanger-dried corn produced an average of 96.9 bushels an acre and the bin-dried corn, 93.7 bushels. The difference of 3.2 bushels an acre, though not large, was

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accompanied by odds of 713 to 1, according to Student's method, which may be considered significant.

In the tests made in 1937, four pairs of entries showed differences carrying odds of 30 to 1 or greater, and one of these was in favor of bin-dried corn. In 1938 two comparisons showed significant differences. One was in favor of bin-dried seed and the other in favor of hanger-dried seed. In 1939 all 10 comparisons showed a yield difference in favor of hanger-dried corn and 6 of them were accompanied by odds sufficiently large to indicate significance.

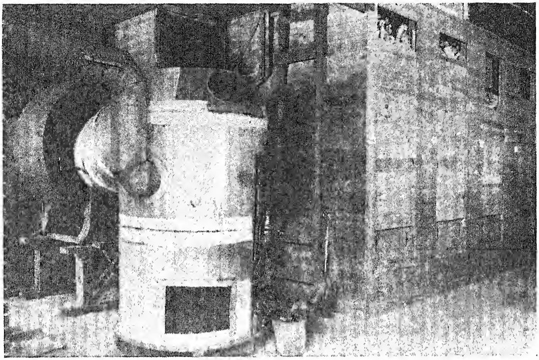

FIG. 1.—A small commercial seed corn drying plant of the bin type. This apparatus, including a five-horse power motor driven fan, takes care of eight bins, each holding 120 bushels of ear corn.

EARS DRIED IN EXPERIMENTAL CHAMBERS

METHODS

Seed ears.—Ears of two commercial hybrids were hand-picked from commercial seed-producing fields in 1937 and 1938 when the grain moisture was about 30%. The ears selected were above average in uniformity, size, and freedom from blemishes as compared to the field run. They were handled carefully to avoid injury to the seed coats and each hybrid was divided at random into three lots of 120 ears each to determine the effect of different rates of drying on internal seed infection.

Drying chambers.—Drying was accomplished in special chambers (Fig. 2). For rapid drying, a small stream of heated air was supplied and the temperature within the chamber was maintained at 106° F. Humidity was not controlled but averaged about 32% relative humidity during the four days in which the corn was dried from 30% grain moisture to 12%.

For a moderate rate of drying, the temperature was maintained near 70° F and the humidity was controlled at 65% relative humidity. The corn dried to 12% in four weeks.

TABLE 1.—*Performance of corn dried somewhat slowly on hangers under favorable conditions compared with corn dried quickly in artificially heated bins, Urbana, Illinois.*

Kind of corn	Drying plant No.	Field stand, %		Yield, bu. per acre			Odds
		Hanger dried	Bin dried	Hanger dried	Bin dried	Amount by which hanger-dried corn exceeded (+) or fell short (−) of bin-dried corn	
				1937			
Commercial Hybrid A	2	96.3	93.0	91.3	91.4	−0.1	1:1
Commercial Hybrid B	3	96.5	93.5	93.8	85.6	+8.2	1666:1
Illinois Hybrid 384	3	95.8	93.5	96.6	92.2	+4.4	30:1
Griffith Yellow Dent	4	94.3	97.0	93.9	88.1	+5.8	262:1
Murdock Yellow Dent	5	93.3	91.8	73.2	71.9	+1.3	5:1
Commercial Hybrid C	8	95.7	91.2	102.2	98.1	+4.1	18:1
Illinois Hybrid 582	8	96.8	95.2	105.8	105.6	+0.2	1:1
Illinois Hybrid 172	8	94.7	93.7	94.2	99.4	−5.2	49:1
Commercial Hybrid D	11	95.8	95.3	93.9	91.0	+2.9	8:1
Average............		95.5	93.8	93.9	91.5	+2.4	20:1†

			1938				
Illinois Hybrid 960	1	90.0*	93.0*	104.7	111.0	−6.3	66:1
Indiana Hybrid 845	1	88.0*	93.0*	113.1	116.3	−3.2	5:1
Illinois Hybrid 582	2	93.0*	86.0*	115.5	106.0	+9.5	666:1
Average............		90.3*	90.7*	111.1	111.1	0.0	——
			1939				
Illinois Hybrid 960	1	97.3	95.5	103.5	95.9	+7.6	344:1
Commercial Hybrid E	2	94.2	90.5	86.7	85.0	+1.7	4:1
Commercial Hybrid F	3	94.3	94.7	97.5	92.0	+5.5	216:1
Illinois Hybrid 751	6	88.8	92.5	94.8	92.4	+2.4	667:1
Commercial Hybrid G	7	92.3	80.7	96.4	89.0	+7.4	49:1
Commercial Hybrid H	8	95.0	94.2	88.8	86.5	+2.3	4:1
Commercial Hybrid C	9	95.8	85.8	101.6	93.3	+8.3	216:1
Commercial Hybrid I	10	85.8	87.5	94.3	88.8	+5.5	4:1
Commercial Hybrid J	11	95.8	95.0	94.1	90.8	+3.3	8:1
Commercial Hybrid K	12	96.3	93.2	96.8	91.2	+5.6	132:1
Average............		93.6	91.0	95.5	90.5	+5.0	9999:1†
Grand average..........		93.9	92.1	96.9	93.7	+3.2	713:1†

*Percentage of strong seedlings on the germinator, rather than field stand.
†Odds calculated on the average.

For slow drying the temperature was kept at 70° F and the relative humidity at 86%. The corn was kept in this chamber for three months at the end of which time it still contained 17% moisture. It was then dried rapidly to 12%. Some ventilation was provided for each of the chambers.

The first lot simulated bin-drying conditions, the second lot was intended to represent first-class hanger-drying conditions as practiced by careful farmers and seedsmen who do not have forced hot-air drying equipment, while the third lot represented poor hanger-drying conditions.

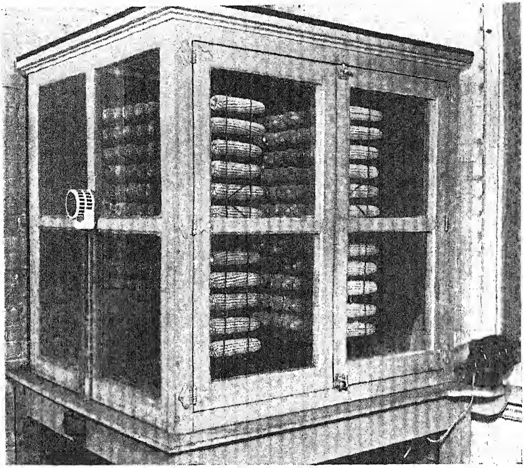

FIG. 2.—One of the experimental drying chambers used. It was equipped for temperature and humidity control, as well as for change of air. Picture shows 120 ears of each of two hybrids slow-dried in 1938.

After the ears were dry they were tipped and butted and eight kernels were removed in a spiral manner from end to end of each ear for determination of disease infection.

Infection determinations.—Seed infection may roughly be divided into two kinds, *viz.*, (a) total, that is, surface plus internal infection; and (b) the more deep-seated infections which remain after the seed has been surface sterilized. Total infection can probably best be determined by placing the unsterilized grain between wet sterilized muslins or fresh paper towels or blotters in a germinator. Results cannot always be read accurately because fast-growing surface contamimates may hide from view more important parasites. Nigrospora, for instance, can rarely be detected as a mycelial growth on a germinator but shows up very well in culture dishes (Fig. 3). *Fusarium moniliforme* (Table 5), *Penicillium*

species, and *Cephalosporium acremonium* readings are higher on unsterilized seed than on sterilized seed. No doubt some of the infection with these organisms is so superficial that it is killed by a surface disinfectant such as mercuric chloride or chlorine solutions.

Since the more deep-seated infections are more important than total infection and since the method is no doubt more accurate for comparative purposes, the percentages of kernel infection were determined by the surface sterilizing and plating method. A dish with eight kernels was prepared from each ear (Fig. 3).

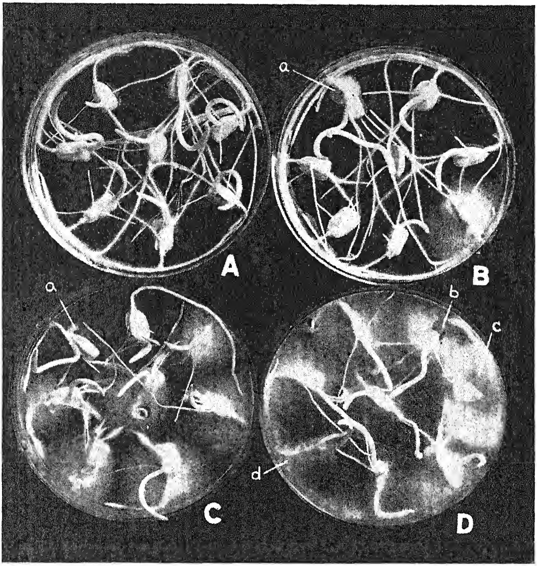

FIG. 3.—Testing for internal seed infection by the plating method.
A, From ears dried in four days, 94.9% of the kernels tested free from infection. B, Dried in one month. C and D, Dried in three months. Names of fungi shown (a) *Cephalosporium acremonium;* (b) *Penicillium sp.;* (c) *Gibberella zeae;* (d) *Nigrospora sphaerica.* All other fungus colonies are *Fusarium moniliforme.*

Yield tests.—Yield tests were conducted on the University farm in hand-planted plots two rows wide by 16 hills long, three kernels per hill, 10 plots of each kind of corn. Acre yields were determined on a uniform moisture basis. Except where mentioned otherwise, the seed was treated with a good organic mercury disinfectant before planting.

DIFFERENCES IN DRYING AND FIELD PERFORMANCE

A composite sample from all the viable ears of each hybrid and of each of the three rates of drying was used in a field test (Table 2). This required only a small part of each ear and the remainder of the ear was available for other field tests (Table 4). A small number of ears had poor germination and were discarded.

The corn which was dried rapidly and that which was dried at a moderate rate produced crops with nearly identical field stands and yields of grain. None of the differences are statistically significant; but when the results from rapidly dried seed were compared with those from the slowly dried corn, there was a statistically significant difference three times in four (Table 2) in favor of the former.

TABLE 2.—*Effect of three different rates of seed drying on resulting field stand and acre yield of several yellow dent corn hybrids, Urbana, Illinois.*

Year*	Hybrid	Rate of drying	Relative humidity while drying, %	Field stand, %	Acre yield, bu.	Difference in yield between fastest and slowest dried seed, bu.
1938	Illinois 960	Rapid	32	97.0	92.1	
		Moderate	65	96.5	92.4	
		Slow	86	92.7	88.0	4.1†
1938	Nebraska 110	Rapid	32	95.4	89.5	
		Moderate	65	95.9	88.1	
		Slow	86	94.0	86.6	2.9
1939	Illinois 960	Rapid	32	93.9	104.4	
		Moderate	65	95.9	106.0	
		Slow	86	84.7	96.0	8.4†
1939	U. S. 13	Rapid	32	94.8	109.6	
		Moderate	65	95.1	107.9	
		Slow	86	82.3	98.0	11.6†

*Year in which field test was made. Seed ears harvested and dried in the previous fall.
†Statistically significant difference.

FUNGUS INFECTION IN SEED

Differences in rapidity of drying had a marked effect on internal fungus infection of the grain (Table 3, Fig. 3). Total fungus infection in corn dried at rapid, moderate, and slow rates was, respectively 5.1, 18.3, and 69.0% of the kernels. The prevalence of the first group of fungi in Table 3, namely, *Fusarium moniliforme*, *Penicillium* species, *Nigrospora* species (*N. sphaerica* and *N. oryzae*), and *Gibberella zeae* was affected much more by differences in drying than was the second group. For instance, internal Penicillium infection was present in a significant amount only in the lots that had been dried slowly. On the other hand, *Diplodia zeae* infections were nearly constant regardless of the rate of drying. However, Diplodia infection in all these ears was very low and the results may not give a true

TABLE 3.—*Prevalence of internal seed infection in kernels of hybrid seed corn ear dried, from 30 to 12% grain moisture, at three rates of drying, viz., four days, one month, and three months.*

Mortality and kind of seed infection	Rate of drying														
	Rapid (4 days)					Moderate (1 month)					Slow (3 months)				
	1937		1938		Average %	1937		1938		Average %	1937		1938		Average %
	Ill. 960 %	Neb. 110 %	Ill. 960 %	U.S. 13 %		Ill. 960 %	Neb. 110 %	Ill. 960 %	U. S. 13 %		Ill. 960 %	Neb. 110 %	Ill. 960 %	U. S. 13 %	
Dead kernels	0.2	1.1	0.1	0.6	0.5	0.1	3.7	0.6	0.4	1.2	2.9	2.9	9.0	4.0	4.7
Fusarium moniliforme	0.2	0.0	0.5	1.7	0.6	8.5	1.5	6.4	3.8	5.1	18.2	4.0	49.9	60.4	33.1
Penicillium spp.	0.0	0.0	0.0	0.3	0.1	0.0	0.0	0.1	0.7	0.2	25.3	18.6	15.9	2.5	15.6
Nigrospora spp.	0.4	0.4	1.6	2.3	1.2	3.9	0.8	1.7	12.0	4.6	2.0	3.2	10.2	17.8	8.3
Gibberella zeae	0.0	0.0	0.0	0.0	0.0	1.6	0.5	1.7	2.3	1.5	0.8	1.3	3.5	12.8	4.6
Cephalosporium acremonium	0.0	0.8	4.7	2.7	2.1	0.5	2.4	7.8	2.4	3.3	0.6	7.9	4.0	7.0	4.9
Diplodia zeae	0.0	0.7	0.6	0.5	0.5	0.1	1.4	1.2	0.0	0.7	0.1	0.0	1.3	1.3	0.7
Other infections	0.0	0.4	0.7	1.1	0.6	0.3	1.6	2.6	7.2	2.9	0.5	1.8	2.6	2.3	1.8
Total infection	5.1					18.3					69.0				

picture of what might happen under other seasonal conditions with greater abundance of Diplodia ear infection.

Increase in dead kernels as speed of drying decreased appeared to be caused by fungus infections. *Fusarium moniliforme*, *Penicillium* spp., and *Gibberella zeae* were the fungi most commonly associated with dead kernels in the test dishes (Fig. 3, C and D).

The classification "other infections" in Table 3 includes Aspergilli, Epicocum, Helminthosporium, Hormoderndrum, and others.

FUNGUS INFECTION AND FIELD PERFORMANCE

Six ears as nearly disease-free as possible and six ears heavily infected with one disease, but all ears having 100% germination, were selected from the individual ear records. These selections were made only in the slowly dried corn because in that group the heavily diseased ears were most abundant and there were also some nearly disease-free ears. Ears showing a high percentage of kernels infected with *Penicillium* spp. were available only in one lot, but tests with *Fusarium moniliforme* seed were made with three lots (Table 4).

TABLE 4.—*Effect of disease infection in hybrid seed corn, all ears dried in chamber operated at 86% relative humidity, when planted in field tests, seed not treated with disinfectant, Urbana, Ill.*

Year	Hybrid	Seed condition	Seed infection, %	Laboratory germination, %	Field stand, %	Acre yield, bu.	Decrease because of disease infection, bu.
1938	Ill. 960	Nearly disease free	2	100	95.3	92.8	—
		Fusarium infected	53	100	93.6	88.6	4.2*
		Penicillium infected	47	100	93.8	89.0	3.8
1939	Ill. 960	Nearly diesase free	2	100	95.6	102.5	—
		Fusarium infected	73	92.5	88.7	96.9	5.6*
1939	U.S. 13	Nearly disease free	3	99.5	98.2	108.1	—
		Fusarium infected	86	99.0	90.3	98.7	9.4*

*Statistically significant decrease.

After the seed from these ears was composited and packaged for planting, similar seed was surface sterilized and tested in petri dishes on potato dextrose agar to obtain a composite test on disease infection. No seed disinfection was used on the field-planted seed.

The identity of the species of Penicillium present was not determined except that they were other than *P. oxalicium*. Had this organism been present in any considerable amount it would no doubt have had a severe adverse effect on the field performance of the plants as judged from other experiments in which this organism was present. The species present in this case caused a decrease in yield of only 3.8 bushels per acre which was not a statistically significant decrease.

Fusarium moniliforme caused a significant decrease in yield in all three of the tests. There is no doubt that strains of this fungus can

materially weaken the seedlings of corn and even kill the germ. On the other hand, it is the writers' opinion that such injuries are rare when well-processed corn that has been treated with a good disinfectant is used for planting. In the present experiments it was impossible to find six severely diseased ears in any one of the 120-ear lots that were dried rapidly. Even in the corn dried at an intermediate rate it was not possible to find six ears so severely diseased as those used in the field test reported in Table 4.

Another experiment conducted for three years, 1936–38, gives further information on the effect of *Fusarium moniliforme* seed infection. Seed of 13 different hybrids was used 200 or more ears of each being rack dried in the Agronomy Seed House similar to the method mentioned earlier in this paper. Ten ears most nearly disease-free and 10 ears with highest *F. moniliforme* infection but with 100% germination were selected from each lot. In some lots it was hard to find 10 ears that were nearly disease-free and the 10 best ears were chosen for the test even though they contained more infection than desired. In some other lots it was not possible to find 10 ears with a very high degree of *F. moniliforme* infection. A composite sample of 200 kernels of each 10-ear group was tested, without seed disinfection, on sterile muslin in a germinator, and 100 kernels of each were surface sterilized with chlorine solution and tested on potato dextrose agar in petri dishes. Comparisons of results with the two methods are given in Table 5. In the field tests, when untreated seed was used, there was an average decrease in yield of 1.8 bushels per acre from *F. moniliforme* seed infection. This decrease is small but statistically significant. When the seed was treated before planting, the difference in yield from nearly disease-free and from Fusarium-infected seed was not statistically significant.

DISCUSSION

In trying to find the reason why the corn grown from seed bin-dried by commercial hybrid seed producers yielded less on the average than that hanger-dried in the Agronomy Seed House, one difference in the seed, aside from speed of drying, was discovered. Unfortunately, most of the seed remnants left after planting had not been saved, but seven entries of the 1939 experiment, both bin- and hanger-dried, were still available when it occurred to the authors to make an examination of the kernels for seed-coat injury. In every case there was decidedly more seed-coat injury in the seed that had been bin-dried and subsequently machine processed than in the grain that had been hanger-dried and shelled by hand. Averaging the seven entries in the bin-dried corn, 3.23% of the kernels had suffered removal of one-fourth or more of the seed coat from the crown. In the hanger-dried corn, only 0.26% were similarly injured. In broken-off tip caps there also was a remarkable difference, the percentages being 2.11 and 0.14, respectively. By tip cap is meant the corky area at the end of the kernel where it is attached to the cob. In addition there were also more minor seed-coat ruptures in the bin-dried seed than in the hanger-dried. It should be recalled that the

separation of ears for hanger and bin drying was made after husking and thus the harvesting method for the two was identical.

TABLE 5.—*Effect of seed infection with Fusarium moniliforme on yield of grain in 13 corn hybrids, using untreated seed and seed treated with a good organic mercury disinfectant, Urbana, Ill.*

Hybrid	*Fusarium moniliforme* seed infection: Germinator test, seed not surface sterilized: Nearly disease-free selections, %	Germinator test, seed not surface sterilized: Fusarium-infected selections, %	Petri dish test, seed surface sterilized: Nearly disease-free-selections, %	Petri dish test, seed surface sterilized: Fusarium-infected selections, %	Decrease (−) or increase (+) in yield from Fusarium infection: Seed not treated, bu.	Seed treated, bu.
			1936			
R4×540	16.0	76.5	0.5	8.5	−1.1	−2.1
Iowa 306	17.0	76.0	0.0	4.5	−2.6	−1.3
Ill. 39	10.0	75.5	0.0	2.0	−3.2	−1.7
			1937			
Ill. 66	5.0	97.5	3.5	65.5	−0.8	0.0
Ill. 428	19.0	97.5	6.0	94.5	−4.5	−4.0
Ill. 710	6.5	86.5	1.0	54.5	+2.1	+0.1
Ill. 758	8.5	93.0	4.0	43.0	+0.3	+1.0
Ill. 762	2.5	94.0	3.0	82.0	−1.5	−4.8
			1938			
Ill. 960	3.0	72.0	0.0	64.0	−2.5	+0.3
Ill. E148	3.5	92.5	1.0	73.0	−3.6	+4.6
Ill. E133	6.0	84.0	1.0	56.0	−2.4	+0.2
Ill. 972	5.0	89.5	2.0	51.0	+0.8	+4.2
Ill. 764	9.0	94.5	4.0	52.0	−4.5	−1.3
Average	8.5	86.8	2.0	50.0	−1.8*	+0.4

*Statistically significant decrease.

In view of the fact that all the seed had been treated for seedling-disease control, the writers are not sure that the difference in seed-coat injury accounted for the differences in yield, but it is the only physical difference that could be observed. The heat used in the drying bins was ordinarily considered safe. According to statements by the producers, the temperature of the air when it entered the drying bins was not over 110° F in any case.

In field tests made from seed corn that had been dried in experimental chambers, there was no significant difference in field stand or yield of grain whether the seed had been dried from 30% moisture to 12% in four days or in one month. The differences in seed infection of 5.1 and 18.3%, respectively (Table 3), probably was immaterial because seed treatment was used, or else was counteracted by other factors. The third group which was dried very slowly showed more seed mortality and poorer field performance than either

of the first two groups. Considerable deterioration from fungi had doubtless taken place while curing and before the seed was treated and planted. Furthermore, much of the disease infection had penetrated deeply so that it probably caused trouble after planting in spite of seed treatment. Even though ears with good germination were selected for planting in these tests, the field stand from slowly dried seed suffered as compared with that from seed dried more quickly.

It is known (1)[3] that at 70° F seed stored with a moisture content of 14% ages faster and looses viability sooner than seed stored at lower moistures. Fungus growth is inhibited and does not become a factor when the moisture is 14% or lower. At higher moistures it is difficult to tell just how much damage is caused by each of the factors, aging and fungus growth. In certain experiments (4), wheat with 22% moisture stored at room temperature became moldy and germinated only 32% at the end of the test period; whereas wheat with the same moisture content and stored in the same way, except that it was treated with carbon tetrachloride vapors, germinated 92%. The vapors inhibited mold growth so that the grain retained a sound appearance. From studies of mold penetration into the corn kernels and observations of germ discolorations from disease infection in the present experiments, it is the opinion of the writers that deterioration of the slowly dried seed was due to activity of fungi to a larger extent than to physiologic aging.

The fungi mentioned by name in Table 3, except *Penicillium* spp. and possibly *Nigrospora* spp., are able to parasitize corn kernels on the immature developing ears. With *Fusarium moniliforme*, in the absence of ear worm or other mechanical damage, early infection is greatly hindered by good husk covering. Early Diplodia and Gibberella infection results in rotted ears that would not be taken for seed. Thus in these ears which were harvested in late September and selected for good husk covering and sound appearance, rapid drying held down internal seed infection to a very great extent. Under some other seasonal conditions infection in corn may be considerably higher, but the difference in internal seed infection between rapidly and slowly dried corn would no doubt still be marked. Furthermore, it is probable that in most commercial processing the ears are not selected as carefully as they were in these experiments and thus somewhat more disease infection may be expected in average commercial bin-dried seed lots than in the rapidly dried seed reported here.

With the exception of *Cephalosporium acremonium*, all of the fungi mentioned acted as storage rots under suitable moisture conditions (3), and with the additional exception of most of the Penicillia they may cause seedling diseases in the planted grain. There is danger from both of these troubles in slowly dried seed corn.

After the seed ears had been dried slowly and selections had been made for nearly disease-free ears, on the one hand, and for ears highly infected with *Fusarium moniliforme*, on the other hand, and the two kinds of seed grown in field plots, significant differences in

[3]Figures in parenthesis refer to "Literature Cited", p. 781

yield were obtained (Table 4). In other experiments with hybrid seed corn rack dried at a more rapid rate, however, the average difference in yield from nearly disease-free seed and from *F. moniliforme* infected seed was only 1.8 bushels when the seed was planted untreated (Table 5). The principal reasons for this small average difference as compared to a difference of 5.9 bushels in open-pollinated corn for a nine-year period ending in 1929 (2, p. 61) are probably three, *viz.*, (a) better resistance to injury from *F. moniliforme* in the hybrids used, (b) less difference in actual infection between the infected and nearly disease-free seed lots in the hybrids used because of less opportunity for selection of wide differences, and (c) favorable spring growing conditions during the three years in which the experiments with hybrids were conducted.

SUMMARY

Bin-dried hybrid seed corn showed no improvement in seed quality over corn hanger-dried under good conditions, as judged in field tests with seed treated for seedling disease control. In seasons when seed infection is more prevalent or when the corn matures more slowly in the fall, bin drying may probably have more value.

In field tests with representative samples of hybrid seed corn from 22 commercial seed production fields dried in two ways, namely, in hangers in the Agronomy Seed House and in drying bins operated by the seed producers, the former averaged 3.2 bushels better in yield over a three-year period. This difference was statistically significant.

Corn ears of several commercial hybrids were hand picked in seed-producing fields when the grain moisture was about 30%. The ears of each hybrid were divided at random into three lots of 120 ears each to determine the effect of different rates of drying on internal seed infection and on field performance when planted.

Chambers with temperature and humidity control were used in which the ear corn was dried down to 12% at three rates of speed, *viz.*, rapid, 106° F, requiring four days; moderate, 70° F, 65% relative humidity requiring one month; and slow, 70° F, 86% relative humidity requiring three months to reduce to 17% moisture after which it was reduced quickly to 12%.

There was no significant difference in yield between corn grown from seed dried at fast and at moderate rates. The slowly dried seed, however, produced reduced stands and yields as compared with either of the other rates of drying. This was attributed largely to fungus infection. The seed had been treated in each case for seedling disease control. The treatment proved adequate for controlling moderate infections, but when the kernels were deeply permeated with fungus mycelia, as in the slowly dried corn, good control was not obtained.

Total kernel infections after surface sterilizing the grain, averaged 5.1, 18.3, and 69.0% for fast, moderate, and slow rates of drying, respectively. The prevalence of *Fusarium moniliforme*, *Penicillium* spp., *Nigrospora* spp., and *Gibberella zeae* was increased the most by slow drying.

Field plots grown from nearly disease-free and Fusarium-infected hybrid corn kernels from ears that had been dried in an identical manner with neither kind treated with a disinfectant, showed some statistically significant reductions in yield from seed infection.

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VARIATIONS IN YIELD AND COMPOSITION OF THE WHEAT PLANT AS AFFECTED BY THE TIME OF APPLYING PHOSPHATIC FERTILIZERS[1]

CHING-KWEI LEE[2]

IT SEEMS to be definitely established that plants take up most of their phosphate supply in the early stages of growth, and it is then that the application of phosphatic fertilizers to a soil needs thorough consideration.

Gregory (3),[3] having worked with maize in sand culture, showed that the first application of phosphate was the most efficient. Later applications, although continuing to increase the rate of growth, tended to become much less effective. Gericke (2), after running a series of water culture experiments, believed that the maximum dry weight of wheat was obtainable when the plants were grown in nutrient solutions for four weeks and then transferred to solutions containing no phosphate. Brenchley (1), working with barley in water culture experiments, found that sufficient phosphate was taken up in the first six weeks to allow the plant to attain its maximum dry weight. The absence of phosphate in the early stages of growth, on the other hand, led to a rapid drop in the ultimate amount of phosphate taken up by the plant.

Owing to the presence of a minute quantity of available phosphorus in any infertile soil, the results obtained from soil cultures are generally regarded as more variable than results obtained from nutrient solutions where the supply of phosphate can be completely controlled in the early stages of growth. Knowles and Watkin (4), in a study of the assimilation of plant nutrients in wheat during growth, found that assimilation of phosphate ceased at two weeks before harvest. The experiment was conducted on a clayey calcareous soil.

The present report is an out growth of pot-culture experiments with wheat growing on a yellow earth deficient in phosphorus. Various quantities of phosphate fertilizer were added to the pots at different times. The concentration of phosphorus in the plant at different stages of growth was determined and the yield analyzed.

EXPERIMENTAL PROCEDURE

The soil selected for this experiment is known as Si-shan-ping clay loam, an old yellow earth located on a narrow horizontal depression on the top of an anticlinal ridge 80 kilos northwest of Chungking in Syzechuan Province, China. As indicated by the following analysis, this soil contains very little available phosphorus:

pH	Total P_2O_5 %	Available P, p.p.m.	Neubuaer value, P_2O_5 mg
4.5	0.08	Trace	−1.95

[1]Contribution from the National Geological Survey of China, Division of Soils, Chungking, China. Published with the consent of the Director of the Survey. Received for publication July 19, 1940.

[2]Soil Chemist. The writer is indebted to Mr. Y. C. Shang for his help in determining phosphorus in plants during the growing stages.

[3]Figures in parenthesis refer to "Literature Cited", p. 788.

3,500 grams of air-dried soil and 1,200 grams of washed sand were placed in common Mitscherlich's pots. With this were mixed in each pot 1 gram of nitrogen in the form of $Ca(NO_3)_2$ and an equal amount of K_2O in the form of K_2SO_4. Phosphate was applied later in a solution extracted from superphosphate, which had a concentration of 1 gram of P_2O_5 in 400 cc.

In each pot were sown 35 seeds which contained 0.80% P_2O_5 (dry basis). Germination proceeded uniformly after 9 days and 30 seedlings were allowed to grow in each pot. All treatments were in triplicate.

At the end of each 30 days one plant was cut from each pot for analysis. The phosphorus content was determined by Denege's colorimetric method (9) and expressed as percentage of P_2O_5 in dry matter. Available phosphorus in the soil was determined by Truog's method (8). Distilled water was used for watering the soil before the phosphate was applied, but rain water was substituted later.

RESULTS AND DISCUSSION

TIME OF APPLYING PHOSPHATE AND YIELD OF WHEAT

To ascertain the effect of time of applying phosphate on the yield of wheat, phosphate solutions containing 1.10 gram of P_2O_5 were added to one series of pots at time of sowing and to other series at intervals of 30 days. The last application was made at March 11, 120 days after sowing.

No difference in growth could be observed when the plants were 30 days old. Wheat was stunted in growth at about six weeks after sowing in pots which received no phosphate, with a brownish discoloration appearing on the tips and margins of the leaves. The brownish color gradually changed into purple and finally colored the whole leaf. Addition of phosphate at any growing stage was followed by an accelerated growth of the plants, but the response was not immediate. Improvement in growth was usually visible about 2 weeks after the application of the phosphate.

Korczewski (6), from the results of water culture experiment with maize, stated that the rate of growth at a given moment of development is determined not only by the actual P_2O_5 concentration in the external medium, but also by the concentration of phosphoric acid during the preceding days of growth. Wheat receiving phosphate 4 weeks later actually gave the same yield at harvest as wheat which received an application of phosphorus at seeding time. Applications made much later than this diminished the yield. The results are presented in Table 1.

Shortage of phosphate in the early stages of growth decreased the number of grains per ear. The time of maturity was also delayed. Ear emergence occurred by the middle of March in wheat which received phosphate at sowing (November 11) and was one week later in wheat receiving phosphorus December 11. Further delay of phosphate application successively caused slower ear emergence and late ripening as well. In fact, normal maturity did not occur in wheat which received phosphate more than 90 days after sowing, the plants remaining greenish in color in both straw and ears until they died. The recovery of phosphate by the tops of plants which received phosphate at sowing was 25.2%. This figure included the phosphorus

originally contained in the seeds. Later application of phosphate caused successively lower recovery.

TABLE 1.—*Yield of wheat in relation to time of applying phosphate.*

	Time of application of 1.10 grams P_2O_5, days after sowing					
	0 Nov. 11	30 Dec. 11	60 Jan. 11	90 Feb. 11	120 Mar. 11	Check, no addition
Weight ears, grams	28.98	27.87	23.70	11.31	3.10	0.75
Weight straw, grams	40.02	40.38	24.50	11.90	4.65	1.63
Total, grams	69.00	68.25	48.20	23.21	7.75	2.38
P_2O_5 in ears, mg	225.2	209.0	177.5	62.4	18.5	3.3
P_2O_5 in straw, mg	52.2	56.2	49.3	50.2	30.1	1.5
Total, mg	277.4	265.2	226.8	112.6	48.6	4.8
P_2O_5 recovered, %	25.2	24.1	20.5	10.2	4.4	—
Average height, cm	121	121	91	75	41	20
No. grains per ear	34	33	27	16	10	6

Examination of the concentrations of phosphorus in the plants 30 days after sowing showed that plants which received phosphate at sowing contained 0.93% of P_2O_5 in the dry matter, while those which received no phosphate contained 0.51–0.55%. Successive determinations of phosphorus in the former case showed that the concentration of P_2O_5 decreased gradually as growth proceeded and declined to a rather steady value of about 0.50% (Table 2).

According to Korczewski (6), the intensity of growth processes which are going on in the plant does not depend directly upon the phosphate concentration outside the plant but upon the amount of phosphoric acid available in cells and growing tissues. Thus, at the earliest stage of growth wheat grows merely at the cost of the accumulated P_2O_5 in the seed. After about 30 days, when the plants have grown bigger and the content of P_2O_5 per unit of dry weight is rapidly diminishing, the direct supply of phosphoric acid by absorption becomes the limiting factor.

As shown in Table 2, when the concentration of P_2O_5 in wheat dropped to 0.51–0.55%, stunting of growth commenced. Further growth of the plant without a supply of available phosphorus from the soil caused successive diminution of phosphate in the plant cells and a purplish discoloration of the leaves characteristic of phosphate deficiency. Addition of phosphate at any stage of growth was accompanied by a marked increase of P_2O_5 in the plant tissues to about 0.90–0.97% and the plant recovered normal growth.

At the end stage of growth, transference of phosphate to the grain is very distinct. The concentration of P_2O_5 in the ears was nearly six times that in the straw. This process, according to Knowles and Watkin (4), proceeded until within about a week before harvest. In their detailed study of the amounts and distribution of phosphorus compounds in wheat during growth (5), they also found that at

harvest three-fourths of the phytin, four-fifths of lipin, and the whole of the inorganic phosphorus was in the ear. In wheat receiving phosphate more than 90 days after sowing and in which the ripening process was not completed, a greater part of the phosphoric acid was retained in the straw.

TABLE 2.—*Concentrations of phosphoric acid in wheat plants which received phosphate at different stages of growth.*

Time of applying 1.10 grams P_2O_5	Percentage P_2O_5 in dry tissue at growing periods, days after sowing					Percentage P_2O_5 at maturity	
	30 Dec. 11	60 Jan. 11	90 Feb. 11	120 Mar. 11	150 Apr. 11	Ears	Straw
Nov. 11, at sowing	0.93	0.83	0.57	0.48	0.46	0.77	0.13
Dec. 11	0.51	0.91	0.77	0.57	0.46	0.75	0.14
Jan. 11	0.55	0.22	0.93	0.83	0.62	0.75	0.20
Feb. 11	0.51	0.20	0.15	0.97	0.75	0.55	0.42
Mar. 11	0.53	0.20	0.16	0.13	0.90	0.60	0.65
No addition	0.51	0.21	0.18	0.17	0.17	0.44	0.09

RATE OF APPLICATION OF PHOSPHATIC FERTILIZER AND YIELD RESPONSE

Si-san-ping clay loam is an old yellow earth containing very little phosphate. P_2O_5 to the amount of 0.1100, 0.2750, 0.5500, 0.8350, 1.1000, and 2.000 grams was added at seeding time. The available phosphorus markedly increased with the increased amount of phosphate solution applied per pot (Table 4). The results differed from the plot experiment of Richer and White (7) where the addition of double or triple amounts of superphosphate showed only small increases in available phosphorus extract.

Almost no yield was obtained where no phosphate was added. Maximum yields seemed to have been obtained when 1.1 grams of P_2O_5 were added per pot. An excess of phosphate, although causing no decrease of yield, showed a diminished return. A higher percentage recovery of P_2O_5 was not found in cases which gave maximum yields. Small doses of P_2O_5 also resulted in little recovery. This was affected by the fixation of phosphate in the strongly acid soil. The results are presented in Table 3.

Deficiency in phosphate delayed maturity. In the pots containing only a trace of available phosphorus, the ripening process was not completed, the ears and straw retaining a greenish color. High concentration of available phosphorus in soils did not effect an abnormal increase of phosphorus concentration in plant cells. Wheat seemed to keep a maximum inside concentration of P_2O_5 at about 0.95% in its earliest stage of growth (Table 4). A lower concentration of P_2O_5 at that time limited the growth in subsequent periods. Transference of phosphate to the grain was also very distinct in wheat suffering from phosphate starvation. The straw retained little phosphorus, while a large portion was accumulated in the grain. Where normal

TABLE 3.—*Rate of application of phosphatic fertilizer and response of yield of wheat.*

	Weight of P_2O_5 added per pot, grams						
	2.0000	1.1000	0.8250	0.5500	0.2750	0.1100	No addition
Weight ears, grams	30.03	28.98	26.55	21.34	6.87	1.53	0.75
Weight straw, grams	40.18	40.02	29.80	26.25	14.84	4.22	1.63
Total, grams	70.21	69.00	56.35	47.59	21.71	5.75	2.38
P_2O_5 in ears, mg	231.0	225.2	193.0	149.9	39.2	9.0	3.3
P_2O_5 in straw, mg	54.4	52.2	35.8	34.6	16.2	5.5	1.5
Total, mg	285.4	277.4	228.8	184.5	55.4	14.5	4.8
P_2O_5 recovery, %	14.3	25.2	27.8	33.5	20.1	13.2	—
Average height, cm	121	121	116	104	75	26	20
No. grains per ear	34	34	22	20	17	6	6

growth was attained, wheat also preserved a definite percentage of P_2O_5 at maturity, i.e., about 0.75% in the ear and 0.13% in the straw. An ample supply of available phosphorus in the soil did not increase these values, but in soils deficient in phosphate these figures declined.

TABLE 4.—*Concentration of phosphoric acid in wheat receiving different amounts of phosphate*

P_2O_5 added per pot, grams	Available P, p.p.m.	Percentage P_2O_5 at different times, days after sowing					Percentage P_2O_5 at maturity	
		30 Dec. 11	60 Jan. 11	90 Feb. 11	120 Mar. 11	150 Apr. 11	Ears	Straw
2.0000.....	202	0.95	0.88	0.64	0.55	0.48	0.77	0.13
1.1000.....	80	0.93	0.83	0.57	0.48	0.46	0.78	0.13
0.8250.....	52	0.93	0.75	0.56	0.38	0.37	0.73	0.12
0.5500.....	30	0.77	0.66	0.51	0.40	0.37	0.72	0.13
0.2750.....	22	0.62	0.53	0.31	0.26	0.25	0.58	0.11
0.1100.....	Trace	0.56	0.39	0.38	0.22	0.21	0.59	0.13
No addition	Trace	0.53	0.21	0.18	0.17	0.17	0.44	0.09

TIME OF APPLYING PHOSPHATE TO SOILS OF DIFFERENT DEGREES OF PHOSPHATE DEFICIENCY AND YIELD OF WHEAT

An additional series of experiments was conducted in which 0.11, 0.275, to 0.550 gram of P_2O_5 were applied at seeding time. A supplementary quantity of P_2O_5, making the total application 1.10 grams per pot, was added at different stages of growth. The plants thus received an equal amount of P_2O_5 but were subjected to different degrees of phosphate deficiency at early stages of growth. The results are presented in Table 5.

TABLE 5.—*Yield of wheat and time of applying phosphate to soils of different degrees of phosphorus deficiency.**

Dates when additional P_2O_5 was added	Weight ears, grams	Weight straw, grams	Total, grams	P_2O_5 in ears, mg	P_2O_5 in straw, mg	Total, mg
0.11 gram P_2O_5 Added Per Pot Before Sowing, Available P Trace, 0.99 gram P_2O_5 Added						
Dec. 11.......	27.28	38.75	66.03	216.9	75.5	292.4
Jan. 11........	23.49	26.28	49.77	178.3	65.8	244.1
Feb. 11........	11.44	14.45	25.89	70.0	59.8	129.8
No addition...	1.53	4.22	5.75	9.0	5.5	14.5
0.2750 gram P_2O_5 Added Per Pot Before Sowing, Available P 22 p.p.m., 0.8250 gram P_2O_5 Added						
Dec. 11.......	28.77	39.80	68.57	209.3	81.2	290.5
Jan. 11........	27.00	36.41	63.41	208.2	73.2	281.4
Feb. 11........	19.17	24.32	43.49	140.0	71.8	211.8
No addition...	6.87	14.84	21.71	39.2	16.2	55.4
0.55 gram P_2O_5 Added Per Pot Before Sowing, Available P 30 p.p.m., 0.55 gram P_2O_5 Added						
Dec. 11.......	29.34	41.35	70.69	229.7	80.1	309.8
Jan. 11........	30.94	40.13	71.07	224.4	80.4	304.8
Feb. 11.......	27.01	37.45	64.46	195.4	82.4	277.8
No addition...	21.34	26.25	47.59	149.9	34.6	184.5

*Wheat sown on November 11.

The presence of a small quantity of available phosphorus in soils increased the efficiency of phosphatic fertilizers applied later. In Table 1 it is shown that where 1.10 grams of P_2O_5 were added 90 days after sowing, the total yield was 23.21 grams. When one-fourth of the phosphate was added before sowing, the yield was nearly doubled, revealing the harmful effect of phosphate starvation in the early stages of growth. A severe shortage of phosphate caused an abnormal decrease of phosphorus concentration in the plant cells and consequently injured them. In soils where there was not a serious deficiency of phosphorus, the decrease in efficiency of later applications of phosphate was less marked.

SUMMARY

Yellow earth, a soil of serious phosphate deficiency, was used in this trial. Pot-culture experiments on the effect of applying a phosphatic fertilizer to wheat gave the following results:

1. Applications of phosphate 30 days after sowing gave the same yield as when the application was made at seeding time.

2. Later applications of phosphate successively caused lower efficiency. The times of ear emergence and ripening were delayed.

3. The concentration of P_2O_5 in wheat tissue was suddenly increased to about 0.95% after each addition of phosphate. A large excess of phosphate present in the soil did not increase the concentration of phosphoric acid in plants above this figure.

4. Where the phosphate was applied at later stages of growth, more phosphoric acid was retained in the straw.

5. A deficiency of available phosphorus in the soil, not only reduced the yield of wheat, but also diminished the concentration of phosphoric acid in the plant cells.

6. The presence of a small amount of available phosphorus in the soil made later applications of phosphatic fertilizer much more efficient.

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EFFECT OF DIFFERENT LIME LEVELS ON THE GROWTH AND COMPOSITION OF SOME LEGUMES[1]

H. B. VANDERFORD[2]

GROWING of legumes for soil building, for pasture, and for hay is a well-established practice and any economic means of increasing the amount and quality of these crops is desirable. Not only has the acreage devoted to legumes in the South been greatly increased in the past few years, but also the problems associated with their culture. Although the importance of sufficient calcium has long been recognized, there are undoubtedly other fertility factors to which leguminous crops are sensitive in southern soils. The response to different soil conditions in the South show wide variation not only among the different legumes, but also with the same legume grown on different soils. Since it has been shown by Albrecht (3)[3] that with soybeans the detrimental effect of soil acidity was brought about not so much by the degree of acidity as by the deficiency of available calcium in the soil, considerable attention has been directed toward the determination of the effect of degree of base saturation on the growth of legumes.

Albrecht and Smith (2) have also reported greenhouse work from which they concluded that in liming and fertilizing the soil, attention must go to the degree of saturation of the soil. Davis and Brewer (4) have shown that application of lime and superphosphate to soils low in calcium content enabled the plant to absorb larger quantities of calcium, phosphorus, and nitrogen. Horner (5) has reported that by raising the base saturation of a soil colloid from 40% to 97%, the total amount of calcium taken up by the crop was more than doubled. In order to determine whether calcium is an important factor in the success or failure of legumes on certain soils of Mississippi, greenhouse and laboratory investigations were conducted on Grenada silt loam soil, using soybeans, Korean lespedeza, and sweet clover as indicator crops.

PROCEDURE

Some of the surface soil of Grenada silt loam, which is a soil developed from Loessial material, was taken from a cultivated field and brought to the greenhouse and prepared for various treatments. The titratible hydrogen was determined by titrating a 10-gram sample (dry weight) with 0.04 N calcium hydroxide from the initial pH, which was 4.7, to 7, using the glass electrode. The treatments consisted of adding re-precipitated calcium carbonate in the amounts necessary to neutralize 25, 50, 75, and 100% of the titratible hydrogen, respectively. For each kilogram of this soil, it took 8, 16, 24, and 32 M.E. of calcium to neutralize 25, 50, 75, and 100% of the titratible hydrogen, respectively. All treatments received a uniform application of 0–8–6 fertilizer at the rate of 500 pounds per acre.

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[3]Figures in parenthesis refer to "Literature Cited", p. 793.

After the addition of lime and fertilizer, a weighed quantity of the mixture was placed in small pots and pans and arranged so that each treatment was replicated four times, including a check series. The moisture content was raised to approximately 20% of the water-holding capacity of the soil and maintained at that level as closely as possible throughout the experiment. A pH determination was made on the soil of each treatment prior to seeding. The five treatments, which included a check, were seeded to soybeans, Korean lespedeza, and sweet clover. The seeding was done in February and the plants were harvested at bloom stage which was the first of May. The above-ground portion of the plants grown on each series was harvested and weighed to obtain yields, and samples of the plant materials were collected and analyzed for calcium, nitrogen, and phosphorus according to the A. O. A. C. methods.

EXPERIMENTAL RESULTS AND DISCUSSION

That calcium does have a decided effect on the growth and composition of legumes is shown in Table 1 and in Figs. 1, 2, and 3. This effect, however, is not the same for all legumes. The yield of soybeans, for example, was only increased from 21.5 grams to 25.5 grams by the addition of calcium carbonate sufficient to neutralize all of the titratible hydrogen; whereas, the yields of lespedeza and sweet clover were increased from 7.4 grams to 21.4 grams and from 8.0 grams to 19.3 grams, respectively, when the same amounts of calcium carbonate were added. These increases expressed on a percentage bases would be approximately 20, 200, and 140% for soybeans, lespedeza, and sweet clover, respectively. Although the lespedeza is usually considered to

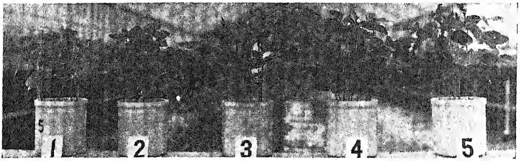

FIG. 1.—Influence of lime on the growth of soybeans. Increasing Ca from left to right: (1) Check; (2) 25% of the titratible hydrogen neutralized; (3) 50% of the titratible hydrogen neutralized; (4) 75% of the titratible hydrogen neutralized; (5) 100% of the titratible hydrogen neutralized.

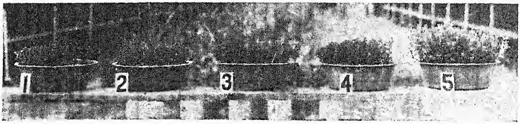

FIG. 2.—Influence of lime on the growth of Korean lespedeza. Increasing Ca from left to right: (1) Check; (2) 25% of the titratible hydrogen neutralized; (3) 50% of the titratible hydrogen neutralized; (4) 75% of the titratible hydrogen neutralized; (5) 100% of the titratible hydrogen neutralized.

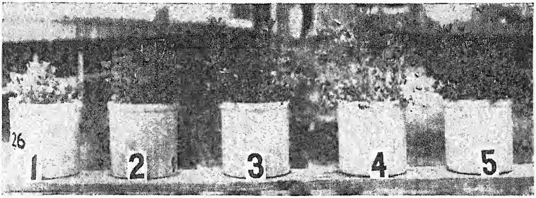

FIG. 3.—Influence of lime on sweet clover. Increasing Ca from left to right: (1) Check; (2) 25% of the titratible hydrogen neutralized; (3) 50% of the titratible hydrogen neutralized; (4) 75% of the titratible hydrogen neutralized; (5) 100% of the titratible hydrogen neutralized.

be an acid-tolerant plant, in this experiment it showed the greatest response to additions of calcium carbonate of any of the legumes tested. On the other hand, sweet clover is usually considered to be very sensitive to a deficiency of calcium in the soil, but in this trial it did not respond as well as lespedeza to additions of calcium carbonate.

TABLE 1.—*The influence of calcium on the yield and composition of soybeans, lespedeza, and sweet clover.**

Pot No.	Treatment per kg of soil	pH	Yield, grams	Plant material: Percentage Ca	Percentage N	Percentage P	Total removed by plants, grams Ca	Total removed N	Total removed P
				Soybeans					
1	Check (no Ca)	4.7	21.5	0.100	1.74	0.162	0.022	0.374	0.035
2	8 M. E. of Ca	5.1	21.9	0.110	1.85	0.145	0.024	0.405	0.031
3	16 M. E. of Ca	6.1	22.4	0.114	2.01	0.117	0.026	0.450	0.026
4	24 M. E. of Ca	6.5	23.0	0.124	2.01	0.119	0.029	0.462	0.027
5	32 M. E. of Ca	7.0	25.5	0.130	1.94	0.114	0.033	0.495	0.029
				Korean Lespedeza†					
1	Check (no Ca)	4.7	7.4	0.071	2.20	0.103	0.005	0.163	0.008
2	8 M. E. of Ca	5.1	9.6	0.099	2.28	0.159	0.010	0.219	0.015
3	16 M. E. of Ca	6.1	13.0	0.104	2.27	0.145	0.014	0.295	0.019
4	24 M. E. of Ca	6.5	14.4	0.112	2.31	0.155	0.016	0.333	0.022
5	32 M. E. of Ca	7.0	21.4	0.133	2.35	0.229	0.029	0.503	0.049
				Sweet Clover					
1	Check (no Ca)	4.7	8.0	0.128	2.41	0.312	0.010	0.193	0.025
2	8 M. E. of Ca	5.1	10.9	0.136	2.69	0.260	0.015	0.293	0.028
3	16 M. E. of Ca	6.1	13.9	0.132	2.75	0.221	0.018	0.382	0.031
4	24 M. E. of Ca	6.5	14.1	0.137	2.71	0.190	0.019	0.382	0.027
5	32 M. E. of Ca	7.0	19.3	0.136	2.46	0.179	0.026	0.475	0.025

*Yields and percentages based on oven-dry weight.
†The Lespedeza was grown only in two replications.

The total amount of calcium removed by all three legumes increased consistently with each addition of calcium carbonate. The total amount of calcium removed by the soybeans varied from 0.022 gram for the check to 0.033 gram for the series to which sufficient calcium was added to neutralize all of the titratible hydrogen, while the amounts removed by the lespedeza and sweet clover varied from 0.005 gram to 0.029 gram and from 0.010 gram to 0.026 gram, respectively. These represent an increase in the amount of calcium absorbed of approximately 50, 480, and 160% for soybeans, lespedeza, and sweet clover, respectively. The lespedeza was, therefore, more efficient in the absorption of calcium than the other two legumes.

The percentage of nitrogen of the plant material did not fluctuate greatly in any case with each addition of calcium carbonate, but the fluctations were less above pH 6 than below pH 6. The total amount of nitrogen removed increased with each added increment of calcium carbonate which would raise the protein content of the hay crop. The most consistent increase was obtained from the plant material of the lespedeza. Calcium seemed to stimulate the fixation of nitrogen very definitely until 50% of the titratible hydrogen was neutralized.

In the case of soybeans and sweet clover, the phosphorus content decreased with each addition of calcium carbonate and the total amount removed by the plants was also less in some cases. The phosphorus content of the lespedeza did not increase consistently with each added increment of calcium carbonate, but the total amount removed by the plants increased definitely. This increase of absorbed phosphorus agrees very favorably with some recent data obtained by Albrecht and Klemme (1) with the same crop. The total amount of phosphorus removed by the lespedeza increased from 0.008 gram for the check series to 0.049 gram for the series that had 100% of the titratible hydrogen neutralized with calcium carbonate. This represents an increase of approximately 512% above the check for the series receiving the maximum amount of calcium carbonate. From the above data, it is obvious that an increase in mineral content as well as yield may be expected from liming Korean lespedeza, even though it is usually considered an acid-tolerant plant. Lespedeza showed more consistent increases in yield, calcium, nitrogen, and phosphorus contents than any plant used in this investigation.

SUMMARY

Some Grenada silt loam which was low in exchangeable bases was treated with calcium carbonate so that 25, 50, 75, and 100% of the titratible hydrogen was neutralized. Soybeans, Korean lespedeza, and sweet clover were grown on the soil which was treated with calcium carbonate in order to obtain five base levels, including a check series for each crop.

The yields of soybeans, lespedeza, and sweet clover increased with increasing additions of calcium carbonate, but the increase was not of a uniform magnitude for each of the three legumes.

The calcium content and the total amount removed by the plants increased with each increasing increment of calcium in all the crops grown.

The percentage of nitrogen did not fluctuate greatly in any case, but the variations were greater below pH 6 than above pH 6. The total nitrogen removed by the lespedeza and soybeans increased with each addition of calcium carbonate.

The phosphorus content and the total amounts removed by the soybeans and sweet clover decreased with increasing increments of calcium carbonate. The total amount removed by the lespedeza increased with each addition of calcium carbonate.

Korean lespedeza gave greater responses to applications of calcium and seemed to be more efficient in the absorption of nutrients than soybeans and sweet clover.

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THRESHING AND CLEANING EQUIPMENT FOR SUGAR BEET SEED[1]

H. W. Bockstahler and Ralph F. Seamans[2]

A NUMBER of seed-harvesting and seed-cleaning problems have arisen in connection with sugar beet breeding investigations of the Division of Sugar Plant Investigations which have led to devising at Rocky Ford, Colo., by the writers special machines to do the work efficiently. In leaf-spot-resistance breeding, inbred strains are produced, necessitating threshing and cleaning of seed from isolated plants or from bagged branches of plants grown in a seed plot. In other cases, group increases, consisting of a few to several hundred plants, are made. Where the quantity of material is not bulky, the seed stalks have been gathered in burlap bags, left to dry, and then threshing and cleaning operations are conducted in the seed house. On the other hand, to produce elite seed, seed plots varying in size from about 1/100 acre to an acre or more are grown. In such cases, the seed stalks are commonly shocked in the field and threshed from the shock. In crossing inbred stains to produce F_1's for test of combinations of inbreds, rows of one inbred are commonly grown adjacent to rows of another inbred. This seed is harvested according to mother strain, shocked to cure, and then threshed. In this breeding work, seed quantities may range from less than an ounce to several pounds and, with large increases, may reach 1,000 pounds. In all operations, due precautions must be taken against any contamination of seed lots.

The machines that have been devised for the various types of seed increases are as follows: (1) Combination thresher and draper for individual plants or small groups of plants, (2) suction seed separator for removal of light, non-viable seed balls, (3) a sugar beet seed polisher to remove corky ridges from seed balls and crush many of the empty seed balls, and (4) a combination thresher and suction seed separator (Fig. 1).

In some of these machines, apparently new principles have been employed. The details of operation are briefly stated and, as necessary, drawings to scale are given. It is probable that, by appropriate adaptations, some of the machines may be useful for other crop plants.

COMBINATION THRESHER AND DRAPER

This machine was devised to thresh and clean, at one handling, plants from which seed yields of an ounce or less, up to several pounds were obtained. To avoid any admixture from previous seed lots run through the machine, attempt was made to have the machine as

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[2]Junior Pathologist and Agent, respectively. The writers wish to acknowledge their indebtedness to G. H. Coons, Principal Pathologist, Division of Sugar Plant Investigations, U. S. Dept. of Agriculture, and to A. W. Skuderna, Manager, Beet Seed Operations, American Crystal Sugar Company, for advice and assistance in the preparation of the manuscript.

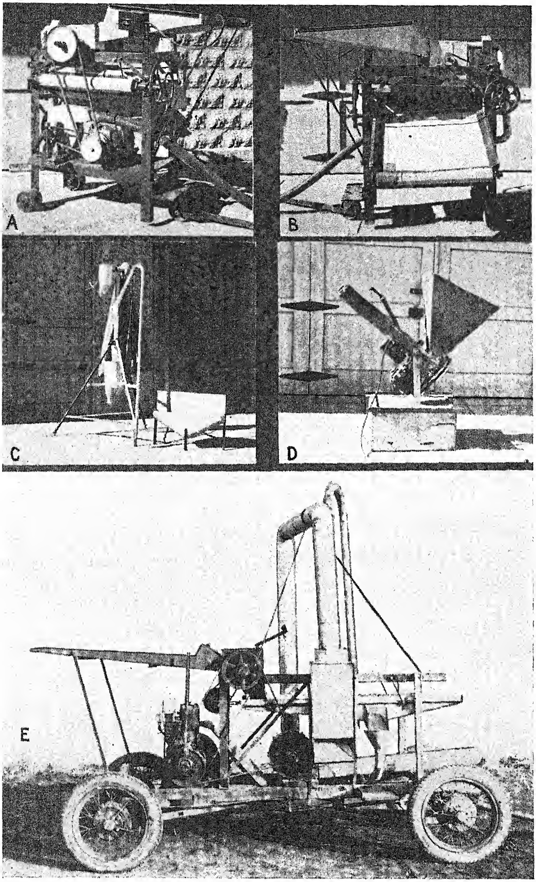

FIG. 1.—Threshing and seed cleaning equipment for sugar beet seed. A and B, front and side views of combination thresher and draper for small samples; C, suction seed separator; D, seed polisher; and E, combination thresher and suction seed separator for use in the seed field with fairly large seed quantities.

nearly self cleaning as possible by sloping or banking off any portions of the frame or operating parts in which seed might lodge. The threshing is accomplished by a saw-toothed cylinder which revolves close to the thresher plate or concave at about 1,200 R.P.M. The cylinder is composed of a number of coarse-toothed circular cross-cut saws 8 inches in diameter, placed along a mandrel. It was found more economical to use saws stamped from 10-gauge black iron than steel saws. The more malleable material had the additional advantage of being less subject to breakage of saw teeth if hard objects, such as stones or thick stems, were encountered.

The saws are spaced about 3/8 inch apart by composition washers 6½ inches in diameter. The saws and washers are arranged on the mandrel shaft at a 5- to 7½- degree angle from perpendicular, in order to produce a weaving motion of the saws across the concave as the cylinder revolves. Suitably beveled end plates, equipped with a lock nut, clamp into place the saws and spacers, tilted as indicated.

The thresher plate or concave is a curved, metal plate, shaped to conform to the saws and slightly longer than the cylinder. Its width is about 1/6 of the circumference of the cylinder. Two 1/8-inch round metal rods are welded horizontally on the threshing plate to form ridges which function to prevent seed stalks from sliding through before being thoroughly threshed. The saw teeth operate about $\frac{1}{16}$ inch from these ridges. The cylinder and concave are enclosed in a black-iron housing so constructed that the top shield may be tipped back on a hinge to facilitate inspection of the drum and the concave. A metal baffle, 2 inches high, extending the length of the cylinder, is riveted on the shield to prevent the revolving cylinder from blowing back dust and fine trash.

The seed stalks to be threshed are fed slowly from the platform into the housing where the cylinder and concave thresh the seed from the stalks. The threshed material, after passing between the cylinder and concave, drops to a coarse mesh shaking screen. Suction from a small fan in the cylinder housing carries dust and fine material into a suitable dust collector. Coarse stems are carried off at the discharge end of the shaker; the seed and fine stems pass through the screen.

Separation of the seed from the fine stems is accomplished by a sloping canvas draper which is placed to operate just below the screen. The draper consists essentially of a 30-inch endless canvas belt which is drawn tightly over a pair of octagonal rollers. Rollers of this shape tend to agitate the canvas belt as it revolves, thus preventing lodgment of seed among the stem fragments. As power is applied by means of a pulley on the upper roller, the canvas belt moves upward. Seed balls bounce or roll into a collecting trough, the stems and trash being carried over the top of the canvas belt. In the present machine, side pieces of the frame are equipped with canvas guards or flaps to prevent seed from finding lodgment in corners or angles of the frame.

This machine has been found to reduce greatly the time required for cleaning small seed lots. The seed as it comes from the draper is free from dust and stems. Further removal of small seeds by sieves, or other means, can readily be accomplished.

SUCTION SEED SEPARATOR

Separation of light, chiefly non-viable, sugar beet seed balls has presented a very difficult problem, almost impossible of efficient accomplishment with larger quantities of seed. An apparatus utilizing an up-draft of air to elevate the seed and to winnow light seed from the heavier, viable component has been devised, and this has been found to work very effectively. The principle can be adapted to similar problems with other seeds or other materials.

The principle of separation is based on the fact that viable seed balls are heavier per unit of volume than non-viable seed balls, and when a sample is discharged into a separation chamber in which the up-draft of a given strength is maintained, the lighter portion is carried upward to a hopper and the heavier seed drops. In operation, it is necessary that gradations of up-draft be obtainable, in order that from sample to sample the proportions removed as "light" seed may be suitably varied. In operation, sugar beet seed is first elevated from the intake hopper on the floor, or other convenient level, into the feed pipe by means of the suction from a vacuum sweeper fan. The seed is then introduced into the separation chamber about half way down from the top of the chamber by means of a tapering conductor which connects, at an angle of approximately 45°, the feed pipe and the separation chamber. The separation chamber is a verticle pipe approximately twice the diameter of the feed pipe.

The up-draft in the separation chamber is variable, its strength being increased or reduced by different settings of air intake openings. Fig. 2 shows the details of the apparatus. The seed hoppers of the apparatus are shaped so as to be self-cleaning and are equipped with close-fitting doors which, with smaller samples, hold the seed in the hoppers until the suction fan is shut off. It is essential that the upper seed hopper have a baffle plate to deflect the light seed from the suction fan.

When a sample of seed is to be cleaned, some estimate of the percentage of seed balls with unfilled locules is obtained by cracking a sample. The apparatus is then given a preliminary setting and the sample run through. Repeated runs can be made, increasing or decreasing the up-draft to secure the type of separation desired.

Some results of sugar beet seed separation are given as illustrative of what the apparatus will do. A seed lot germinating 86% and producing 158 sprouts per 100 seed balls was put through the suction separator. The lighter portion germinated 59% with 68 sprouts per 100 seed balls and the heavier portion 92% with 187 sprouts per 100 seed balls. Of greater interest, however, are the separations possible with seed lots so low in germination as to be practically unusable for planting with the drill. A seed lot germinating 33% and producing 56.5 sprouts per 100 seed balls was separated into two portions. The lighter portion germinated only 2%, with 2 sprouts per 100 seed balls; and the heavier portion, 53%, with 84 sprouts per 100 seed balls. Successive re-separations could have been given this seed lot to raise the germination percentage, but such additional handlings probably would have involved some loss of viable seed by carry-over with the lighter portions.

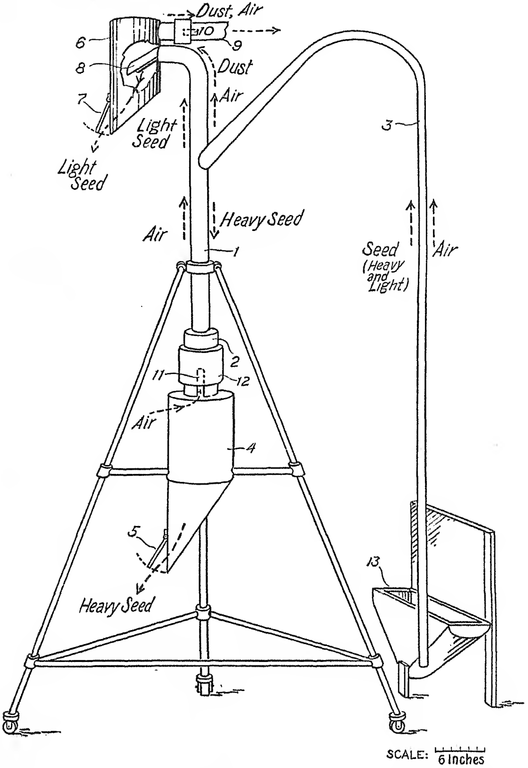

FIG. 2.—Detail drawing of the suction seed separator. Up-draft from a vacuum sweeper fan connected to the upper part (9) is subject to primary regulation by the sleeve-covered slot (10). This draft elevates seed to be separated in the intake pipe (3), carrying it to the separation chamber (1). The light seed is carried to the upper hopper (6), a baffle deflecting it from being drawn into the fan. The sleeve (12) covering the lower slot (11) gives additional regulation of the draft in the separation chamber. The lower seed hopper for heavy seed (4), as well as the upper hopper, are equipped with close-fitting swing doors which remain closed with small quantities of seed until the suction fan is shut off. The small metal seed bin (13) has sloping sides and stands at such height that all seed dumped into it is elevated when suction is applied.

Something of the weight differentials encountered in sugar beet seed balls is shown by the following data obtained after polishing and suction separating a sample of low germinating seed. The average weight of 100 seed balls of the seed as it came from the draper was 1.335 grams. After polishing, the seed was separated into light and heavy fractions. One hundred seed balls of the light fraction weighed, as an average, 0.83 gram; while 100 seed balls from the polished, heavy fraction averaged 1.94 grams. The light fraction was then re-polished and re-separated. One hundred seed balls of the light fraction obtained by re-separation weighed 0.612 gram, and 100 seed balls from the heavy fraction after re-separation 1.310 grams. The relative proportions of seed obtained after these handlings were noted. The first polishing and separating divided the sample into two fractions, approximately equal in weight. The light seed after re-polishing and re-separation was, with one setting of the up-draft, divided 74% light seed balls, 26% heavy; while with another run, with slightly different setting as to draft, the separation was 63% light, and 37% heavy.

SUGAR BEET SEED POLISHER

This machine was devised to remove excess corky tissue from the seed balls and to crush light, empty seed balls. By removing excess cork from the seed balls, separation of the light, barren seed from the heavy seed can be more readily accomplished by means of the suction seed separator.

The polisher (Fig. 3) consists essentially of a helicoid feed mechanism to advance the seed from the hopper into a cylindrical chamber. A rotating shaft which is studded with short, steel pegs runs the length of the cylindrical chamber. The function of this studded shaft is to stir the seed and advance it through the cylinder. The pegs move with enough clearance so that seed does not wedge between them and the wall. As the shaft rotates, the seed balls within the chamber are ground against each other. After traveling the full length of the cylinder, the polished seed balls spill out at the end. The rate of movement of the seed through the cylinder is determined by the angle of elevation of the cylinder. A simple ratchet device serves to set the machine in the desired position.

In changing from one seed lot to another, the seed chamber can be completely cleaned by lowering the discharge end and allowing the machine to run empty for a brief period. The machine is a separate unit and operates equally well with relatively small quantities of seed or with continuous flow of seed from the hopper. The seed must travel the full length of the cylinder before being discharged, thus giving uniformity of treatment.

Results obtained with two seed lots are given below as examples of the improvement obtainable by polishing treatment and from combining this treatment with subsequent suction seed separations. The figures in parentheses denote the germination percentages found for the samples.

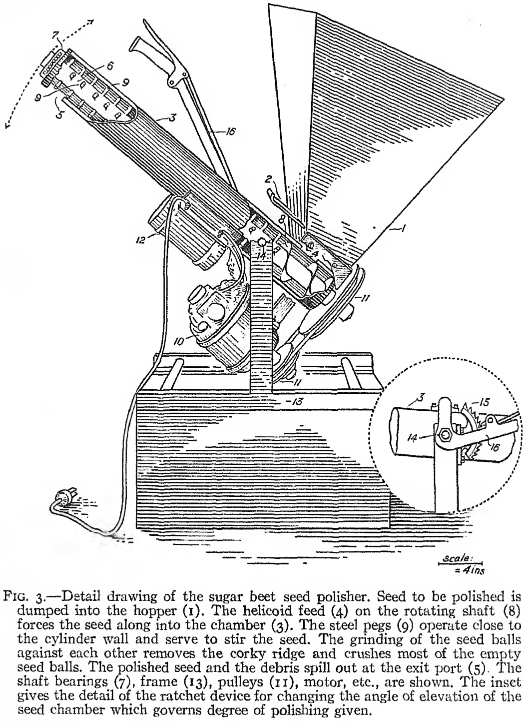

FIG. 3.—Detail drawing of the sugar beet seed polisher. Seed to be polished is dumped into the hopper (1). The helicoid feed (4) on the rotating shaft (8) forces the seed along into the chamber (3). The steel pegs (9) operate close to the cylinder wall and serve to stir the seed. The grinding of the seed balls against each other removes the corky ridge and crushes most of the empty seed balls. The polished seed and the debris spill out at the exit port (5). The shaft bearings (7), frame (13), pulleys (11), motor, etc., are shown. The inset gives the detail of the ratchet device for changing the angle of elevation of the seed chamber which governs degree of polishing given.

Seed Lot A

Original (33%): Suction-separated into light (2%) and heavy (53%).

Original (33%): Polished, suction-separated into light (16.5%) and heavy (56%).

Light seed (16.5%): Polished, suction-separated into light (7%) and heavy (30%).

Seed Lot B*

Original (30%): Polished, then suction-separated into light (20%) and heavy (74%).

Light seed (above) (20%): Re-polished, re-separated into light (12%) and heavy (62%).

*In this series, seed balls were soaked a few hours in running water prior to putting on blotters to germinate.

COMBINATION THRESHER AND SUCTION SEED SEPARATOR

To provide a thresher and cleaner which could be used with relatively large-sized seed plots, a machine was built in which the suction seed separator was made a part of the field threshing outfit (Fig. 4). The threshing outfit consisted of a 12-inch saw cylinder and concave, as previously described, and a shaking screen. The larger stems and trash were discharged from the screen, the sugar beet seed and small stems passing through. A gathering pan, placed beneath the screen, was so shaped as to direct the flow of screened material to the intake hopper of the suction seed separator. The entire equipment was

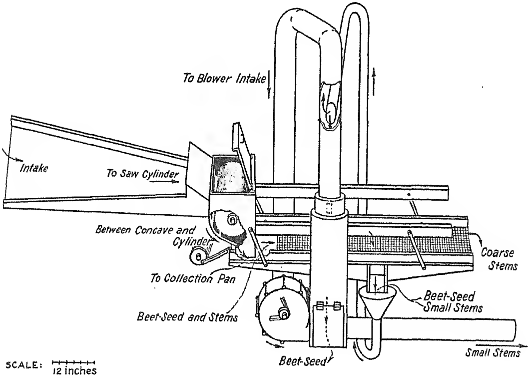

FIG. 4.—Diagrammatic sketch of working parts of the combination seed thresher and suction seed separator. Threshings from cylinder and concave are screened by the shaking screen, coarse material passing over. The screened seed and such stems and trash as pass through the screen move to the suction separator intake, which is also an intake for air for the blower. The up-draft in the separation chamber carries light material upward, the heavier material, chiefly seed, collecting in the seed hopper. The strength of the up-draft can be regulated by size of the opening in an air intake above the seed hopper. The small stems and light debris are blown out of the large pipe which extends horizontally to the right. Power for operation of the machine comes from a small gasoline engine. The whole apparatus is mounted on a 4-wheel trailer (cf. Fig. 1, E.).

mounted on the frame of a four-wheeled trailer. The motive power was supplied by a small gasoline engine.

In operation, the separator drafts were so adjusted that leaves, small stems, and debris, as well as very light seeds, which comprise from 25 to 35% of the bulk of field-run from the thresher, were removed. Close separation of the sugar beet seed into an acceptable heavy fraction and a light fraction to be rejected was left for subsequent seed-house handling with the suction seed separator. Under actual field conditions, it was found that this machine easily handled an acre per day of well-cured sugar beet seed from the shock.

The machine has utility for experimental plantings or for small acreages of elite seed, for which a light, portable outfit is needed. It is probable that the separator principle could be adapted to other similar jobs in which a light fraction is to be removed as a field operation from the threshed material.

GENETIC STUDIES OF HEAT AND DROUGHT TOLERANCE IN MAIZE[1]

E. G. Heyne and Arthur M. Brunson[2]

THE recent drought years in the Midwest have increased interest in developing new strains of corn which are more tolerant to drought. Hybrid corn in several instances has shown less injury under adverse weather conditions than have open-pollinated varieties. Although tolerance to drought is representative of a group of complex characters which are difficult to analyze, it is important that the plant breeder have more information concerning the mode of inheritance of such characters as an aid in carrying out a successful breeding program.

Preliminary observations have shown that striking differences occur among Kansas inbred lines of maize in reaction to drought. A complex character like drought resistance in maize is influenced by many genes which may be located in any or all of its 10 chromosomes. Hybridization with cultures containing markers for the several linkage groups, however, should indicate the location of some of the more important genetic factors influencing drought behavior.

The purpose of this study was to obtain fundamental information on the mode of inheritance of drought resistance. A study of its inheritance is difficult or impossible, except under controlled conditions, as this character is greatly influenced by several environmental factors.

Hunter, Laude, and Brunson (5),[3] and Heyne and Laude (4) reported that it was possible to distinguish among strains with respect to drought tolerance by testing seedling corn plants under controlled conditions. They obtained essentially the same order of relative resistance among strains when seedlings were subjected to artificial heat as was noted for the mature plants subjected to drought and heat in the field. In Kansas, extremely high temperatures seldom occur over a protracted period except when accompanied by deficient soil moisture. As a result it usually is impossible to differentiate accurately in the field between injury due to high temperatures and that due to insufficient moisture. The studies referred to above (4, 5) indicate that corn seedlings subjected to high temperature and low humidity under controlled conditions give a good index to the field behavior of the full-grown plants under the more complex natural conditions of a hot, dry summer. Consequently, the classification of drought resistance reported in this paper is based almost entirely upon the reaction of seedlings to high temperatures.

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[1]Cooperative investigations of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Kansas Agricultural Experiment Station, Manhattan, Kans. Contribution No. 299 from the Department of Agronomy. Received for publication, August 10, 1940.

[2]Junior Agronomist and Agronomist, respectively, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

[3]Figures in parentheses refer to "Literature Cited", p. 814.

TABLE 1.—*Drought-resistant inbred lines of maize and their behavior to natural and artificial drought.*

Inbred line	Generations selfed	Genetic constitution of the aleurone and endosperm	Height in 1937, inches	Maturity	Drought resistance in field, rank	Heat resistance in laboratory, rank	Varietal source
BS1	8	A_1 A_2 C R Pr Su y	50	Early	5	5	Blue Squaw
K10	4	A_1 A_2 c r Pr Su y	58	Medium	1	1	Pride of Saline
K39	5	A_1 A_2 C r pr Su y	64	Late	4	4	Pride of Saline
K201A	2	A_1 A_2 c r pr Su Y	85	Late	2	3	Midland
K201B	2	A_1 A_2 c r Pr Su Y	85	Late	2	2	Midland

MATERIALS AND METHODS

Strains of maize differed in their reaction to the shortage of soil moisture and high temperatures that occurred at Manhattan, Kansas, in 1936. Some inbred lines in the corn breeding nursery succumbed rather early, while others endured the drought to a remarkable degree. Although many strains failed to reach the tasseling stage, some were able to produce a few grains despite the adverse weather conditions. Five of these outstandingly resistant Kansas inbred lines were used as drought-resistant parents in crosses with susceptible genetic testers made in the winter of 1936–37. The five inbred lines are described in Table 1.

The drought resistance of K201A and K201B in the field is rated the same as they came from the same 1936 ear row. After an additional generation of selfing, however, K201B was noticeably more tolerant to controlled high temperatures than was K201A. The early inbred BS1 probably is not so much drought enduring as it is drought escaping, being so early that pollination takes place before the most severe weather conditions occur. K10 is the outstanding inbred line of the group in heat and drought tolerance.

Twenty-seven genetic testers carrying genes marking the 10 chromosomes in maize, 10 translocation stocks, and 4 sweet corn inbred lines[4] were used as the susceptible parents.

The genetic tester and translocation stocks used in the experiments are listed in Table 2. The Kansas inbred lines were crossed with these testers in the winter of 1936–37 and backcrosses were made in the summer of 1937. In addition, crosses were made between inbred lines and between single crosses of known reaction to high temperatures.

TABLE 2.—*Genes and translocations used as testers in crosses with heat- and drought-resistant Kansas inbred lines of corn.*

Chromosome and linkage group	Gene and symbol
1 *P-br*	P, pericarp and cob color; f_1, fine stripe; T1-4a; T1-4b.
2 *b-lg*$_1$	lg_1, liguleless; gl_2, glossy; T2-4b; T2-9a.
3 a_1-ts_4	na_1, nana; ts_4, tassel seed; T3-5b.
4 su_1-*Tu*	su_1, sugary; gl_3, glossy; T2-4b; T4-6a.
5 *pr*-v_2	a_2, anthocyanin (plant and aleurone color); pr_1, aleurone color; T3-5b; T5-7.
6 Y_1-*Pl*	Y_1, endosperm color; *Pl*, plant color; T4-6a; T6-9b.
7 *ra*-gl_1	gl_1, glossy; T5-7.
8 ms_8-j_1	ms_8, male sterile; T8-10b; T8-10c.
9 *c-sh-wx*	*c*, aleurone color; *sh*, shrunken; T2-9a.
10 *r*-g_1	*r*, aleurone color; T8-10b; T8-10c.

During the winter of 1937–38 seedlings of the backcross progenies and of the hybrids were subjected to controlled high temperatures. A room heated with thermostatically-controlled electrical units, constructed by the Agronomy Department, Kansas State College, was used in making all tests. Seven corn seedlings per pot were grown in 4-inch, unglazed clay pots containing a uniform soil mixture. Four or more pots of each strain of 20-day-old seedlings were distributed

[4]Genetic testers were furnished by Dr. E. G. Anderson, California Institute of Technology; Dr. A. A. Bryan, Iowa State College; and Dr. C. R. Burnham, University of West Virginia. The sweet corn lines were obtained from the Minnesota and Purdue Agricultural Experiment Stations.

at random in this room where they were exposed for 5 hours to a temperature of 127° to 130° F and a relative humidity of 30%. The soil was kept moist throughout the period the plants were subjected to heat. The measure of differential injury used was the estimated amount of exposed leaf and sheath tissue killed by the third day after treatment. On the tenth day after treatment, the number of plants killed was recorded and notes were taken on the recovery of the living plants.

EXPERIMENTAL RESULTS

INHERITANCE OF DROUGHT RESISTANCE

Crosses made between inbred lines of corn of known behavior to drought included combinations between resistant × resistant lines, resistant × susceptible, and susceptible × susceptible. The injury from controlled high temperature to five inbred lines and crosses among them is shown in Table 3. The general level of injury was low due to moderate temperatures during these tests.

The resistant × resistant cross was as resistant as its parents and was the most resistant of the crosses. In other tests at higher temperatures it was superior in drought resistance to the parents. The injury to resistant × susceptible crosses was variable, but resistance tended to be partially dominant. In the cross between the two susceptible lines, K249 and P39, the F_1 had as much tissue killed as did the two inbred parents, but fewer plants were killed. In the cross P39 × P51, the F_1 (Golden Cross Bantam sweet corn) was as susceptible to heat as the parents were, which shows that heterosis, *per se*, does not necessarily make the F_1 heat tolerant. Not all crosses reacted similar to those shown in Table 3. K249, when crossed with lines classified as being intermediate in drought resistance, produced plants that were as susceptible to heat as was K249. Line K249 appeared to carry factors for leaf burning which were often expressed in the F_1. K10 apparently has a dominant gene or genes for heat

TABLE 3.—*Comparative heat injury to seedlings of drought-resistant and drought-susceptible inbred lines and crosses among them after controlled high temperature treatment.**

Strain	Drought classification	Tissue killed, %	Plants dead, %	Recovery
K10	Resistant	6	0	Good
K148	Resistant	4	0	Good
P39	Susceptible	39	21	Poor
P51	Susceptible	48	33	Poor
K249	Susceptible	42	13	Live plants recover quickly
K10×K148	Resistant×Resistant	5	0	Excellent
K10×K249	Resistant×Susceptible	6	0	Fair
K10×P39	Resistant×Susceptible	15	0	Fair
K148×K249	Resistant×Susceptible	25	0	Slow recovery
K148×P39	Resistant×Susceptible	10	0	Fair
K249×P39	Susceptible×Susceptible	43	2	Very yellow: slow recovery
P39×P51	Susceptible×Susceptible	50	35	Poor

*Average of three experiments.

tolerance, as shown by its consistent tendency to increase the heat tolerance of the crosses in which it is involved.

The inheritance of heat tolerance also was studied in the three possible double crosses among three single crosses of known reaction. The three single crosses used had a wide range in heat tolerance. The double crosses and single crosses were tested at the same time. The data presented in Table 4 show that the double crosses differ in heat tolerance. The range in tissue injury was small, but there were large differences in the percentages of plants killed by the treatment. The double crosses were intermediate between their parental single crosses in heat tolerance.

TABLE 4.—*Comparative heat tolerance of seedlings of single crosses and double crosses under controlled high temperature conditions.*

Strain	Drought classification	Tissue killed, %	Plants dead, %	Recovery
KYS×38-11	Resistant	85	14	Fair
Hy×R4	Intermediate	94	23	Good
P39×P51	Susceptible	100	88	Poor
(KYS×38-11)×(Hy×R4)	Resistant×Intermediate	94	24	Good
(KYS×38-11)×(P39×P51)	Resistant×Susceptible	91	33	Fair
(Hy×R4)×(P39×P51)	Intermediate×Susceptible	96	45	Fair

LINKAGE EXPERIMENTS

In testing for the possible association of major genes for heat and drought tolerance with particular chromosomes, the Kansas drought-resistant inbred lines were crossed with stocks carrying genetic factors that could be identified by endosperm or seedling characters. Such factors were not available in chromosome 8, and the initial cross involving chromosome 3 was unsuccessful. The data obtained from the heat tests of backcross progenies of the crosses made are shown in Table 5.

Drought-resistant inbred lines also were crossed to lines carrying translocations and the F_1 plants were outcrossed to suitable stocks. These populations also were tested under controlled heat conditions, but no differences were observed. The backcrossed populations were planted in the field in 1939, but the growing conditions were so severe that it was impossible to classify the pollen for sterility. The use of translocation stocks is an additional tool for studying the inheritance of genes controlling quantitative characters, its value having been demonstrated in disease-resistance studies reported by Burnham and Cartledge (1).

The significance of the differences between the percentages of tissue injury in the segregating populations was determined by comparing the F values computed from analysis of variance of these data with those in Fisher's (2) table of F values. The experiments were set up so as to measure any significant differences between the gene pairs tested, between the tests, and in interaction between genes and tests. When the two classes of segregates from a cross differed significantly

in their reaction to high temperatures, it would indicate a possible linkage of the qualitative factors studied with those controlling tolerance to heat. There would be no interaction if all pairs tested were alike in their reaction to controlled high temperatures. A significant discrepancy would indicate one of two possibilities: (a) The pairs differed in relative percentage of injury at various temperature levels, or (b) as different parents were used, it might show that some lines reacted differently from others. The percentage of plants killed was not analyzed because it was not as good a measure of difference as percentage of leaf tissue burned.

TABLE 5.—*Relation of heat tolerance to genes in eight linkage groups in maize in progenies obtained by backcrossing the F_1 plants of susceptible testers×resistant inbreds to the susceptible testers.*

Genes tested		Tissue killed, %		F values from an analysis of variance of the data on tissue injury			Plants killed, %	
X	x	X	x	Computed	5%	1%	X	x
				Chromosome 1				
F_1	f_1	88	92	3.10	4.41	8.28	16	50
				Chromosome 2				
Gl_2	gl_2	70	46	11.87†	4.75	9.33	18	9
				Chromosome 4				
Su_1	su_1	87	95	29.30†	3.89	6.76	42	72
				Chromosome 5				
A_2	a_2	67	72	2.23	4.03	7.17	17	11
Pr	pr	79	88	20.39†	4.03	7.17	21	33
				Chromosome 6				
Y_1	y_1	78	83	1.74	4.26	7.82	7	11
				Chromosome 7				
Gl_1	gl_1	92	73	77.00†	4.03	7.17	34	24
				Chromosome 9				
Sh	sh	62	65	1.44	4.17	7.56	4	11
C	c	87	93	6.80*	4.08	7.31	53	71
				Chromosome 10				
R	r	90	92	1.60	4.03	7.17	55	61

*Significant difference.
†Highly significant difference.

No significant difference was observed between the gene pairs tested that are located on chromosomes 1, 6, and 10, as shown in Table 5. Significant differences in heat tolerance were obtained in segregating families involving gene pairs located on chromosomes 2, 4, 5, 7, and 9. These differences are discussed under their respective linkage groups.

Linkage group 2.—Two genes, lg_1 and gl_2, were used to determine whether genes controlling drought resistance are located on this

chromosome. Although the glossy factor entered the cross from the susceptible parent, the glossy segregates were more tolerant to heat than the non-glossy segregates as indicated by the highly significant difference. The percentage of survival also favored the glossy seedlings. The resistant inbred parent, however, was considerably more resistant than the glossy linkage tester used as the other parent of the original cross. The surface of the leaves on the glossy plants might reflect more heat rays than the leaves of the non-glossy plants, keeping the leaves cooler and causing less damage. It is also possible that the abnormal leaf surface of the glossy plants might affect transpiration rates and thereby result in the cooling effect of evaporation, or it might alter the rapidity with which lethal dessication is reached. Obviously the differential injury observed is due to morphological dissimilarity and not to genetic linkage.

Tests involving liguleless-1 indicated no association between this locus and heat reaction.

Linkage group 4.—The pair of genes determining the sugary or starchy texture of the endosperm is located in this linkage group. The sugary gene (su_1) when homozygous produces the endosperm characteristic of sweet corn. Extensive data from five segregating progenies in 32 tests show that the sugary factor is associated with heat susceptibility. Although only a small difference in percentage of leaf burning is shown in Table 5, it is highly significant. The seedlings from the sugary kernels had a much lower survival value than did the seedlings from the starchy kernels. Typical pots from segregating progenies are shown in Figs. 1 and 2.

Crosses were made in which gl_3 and su_1 were contributed by the susceptible parent. Since these two genes are about 40 units apart on

FIG. 1.—Effect of heat on maize plants segregating for starchy and sugary kernels. The parents are represented by the first and third pots, and the F_1 is between them. The starchy and sugary segregates resulting from a backcross to the *susu* parent are represented by the *Susu* and *susu* plants, respectively.

FIG. 2.—Relative heat tolerance of a starchy inbred and sugary translocation and the resulting progeny when outcrossed to a sugary stock. PS10 is the resistant parent, T4-6a is the susceptible translocation parent. The third pot from the left, *susu*, is the stock to which the F_1 (not shown) was outcrossed. The four pots on the right represent the segregating progeny, *Susu* designating plants from the starchy segregates and *susu* those from the sugary segregates.

the chromosome, frequent crossovers would be expected. Starchy glossy, starchy non-glossy, sugary glossy, and sugary non-glossy plants were tested at the same time. The sugary seedlings in both cases were more susceptible than the starchy segregates. There was no significant difference in heat tolerance between the starchy glossy plants and the starchy non-glossy plants. The sugary non-glossy plants, however, were slightly more resistant to heat than the double recessive condition, *su* gl_3. This is not in agreement with the apparent morphological relation of glossy leaves with heat tolerance obtained with gl_1 and gl_2.

Sweet corn as a class is generally more susceptible to drought injury than is dent corn, which suggests that the sugary gene itself may be responsible. This was indicated when plants heterozygous for translocation stock T1-4a were grown to the pollen shedding stage. The translocation T1-4a, heterozygous for sugary (*Susu*), was crossed to a resistant inbred line (*SuSu*). The sugary condition was not expressed in the F_1, but one-half of the ears from F_1 plants outcrossed to *su* stock segregated for sugary endosperm. When the sugary and starchy segregates from one of these segregating ears were tested, the seedlings from the sugary kernels were more heat susceptible. The outcross, not involving the *su* gene, also was planted and subjected to heat. The 16 most resistant plants from 56 tested were transplanted and grown until they shed pollen. Only 12 plants lived. If a gene responsible for heat susceptibility is located on chromosome 4 near the translocation, one would expect all the plants to be normal; however, 7 of the 12 plants were semisterile and five normal. Although small numbers were used, it indicates that heat susceptibility is not due to genes on chromosome 4 other than the factor pair *Susu*.

It is probable that *su* gene itself affects drought tolerance in a manner similar to that of other genes in maize that are known to have manifold effects on unrelated structures or functions of the plant. In the tests conducted, no sweet corn lines were found to be resistant to heat.

Haber (3) exposed 20-day-old seedlings to controlled high temperature and low humidity and observed differences in resistance to heat among sweet corn strains, but the most resistant strains of sweet corn were not so resistant as resistant strains of dent corn. If the *su* gene is responsible for the lower resistance to heat, it will be a limiting factor in the production of a sweet corn possessing as high a degree of resistance as is found in lines of starchy corn.

Parallel crosses made in this experiment indicate that the parental inbred lines differed in genetic factors influencing reaction to heat which they transmitted. When two inbred lines were crossed on the same sugary tester and backcrossed to the same stock, evident differences occurred in the reaction of the progenies to heat. This difference is illustrated clearly in Fig. 3. The time of planting and treatment were identical. K10 transmitted more heat resistance to its progeny than did BS1. Even the plants from the sugary kernels showed considerable resistance to heat when K10 was involved, while the plants from sugary kernels were killed when BS1 was used as a parent. Line K10 showed more resistance to heat than did BS1 when subjected to the same conditions. Evidence of a wide range of heat and drought resistance in maize, together with proof that differences are inherited, indicate that progress can be made in breeding better heat- and drought-resistant strains.

Linkage group 5.—The behavior of heat tolerance was determined in relation to two genes in this group, a_2 and *pr*. The data presented in Table 5 indicate that the A_2, a_2 pair of genes probably is inherited independently of heat tolerance. Although the a_2 tester used was one of the testers that gave an intermediate reaction to controlled high temperatures, enough plants were tested so that even a loose linkage should have shown a significant difference as determined by analysis of variance.

The seedlings involving the *Prpr* pair of genes gave highly significant results for heat tolerance. In the cases studied *Pr* came from the resistant parents and the *Pr* segregates produced the most resistant seedlings. The survival value is also in favor of the *Pr* plants.

Linkage group 7.—As shown in Table 5, gl_1 appears to affect the relative heat tolerance of corn seedlings. In segregating progenies the glossy seedlings were more resistant to heat than the non-glossy seedlings. This substantiates the results with linkage group 2 in which the glossy seedlings, due to gl_2, also were the more resistant, although the glossy character came from the susceptible parent.

Since the glossy testers used as parents were more susceptible to heat than the non-glossy resistant inbred lines, it would be expected that if a linked factor for heat behavior were involved, the glossy seedlings should be most susceptible in the segregating progenies resulting from backcrosses to the recessive parents.

Linkage group 9.—The relation of heat tolerance to two pairs of

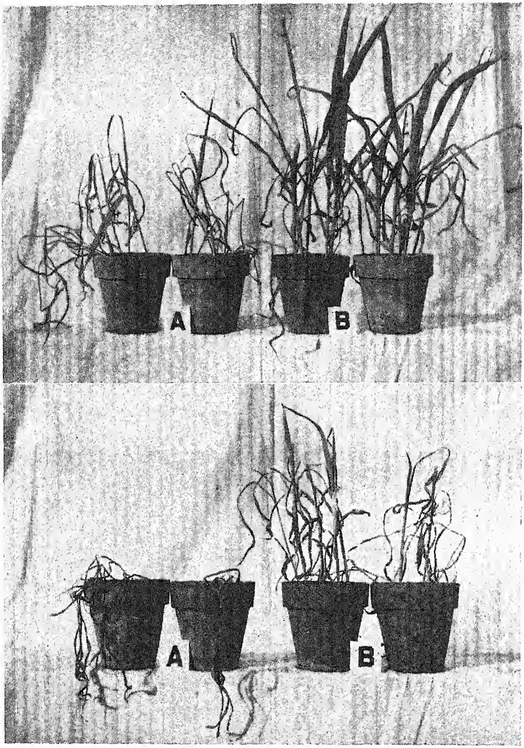

FIG. 3.—Effect of different parents on the heat resistance of their progeny. The plants were grown and treated under comparable conditions. Heat resistance transmitted by K10 (upper) is much more pronounced both in sugary segregates (A) and starchy segregates (B) than that transmitted by BSl (lower).

genes, *Shsh* and *Cc* on this chromosome was studied. The shrunken factor causes the endosperm to collapse during drying at maturity and the seedlings are somewhat retarded in early stages of growth. Although the seedlings from shrunken kernels may have been at a

disadvantage, no significant differences between this pair of genes in percentage of heat injury occurred.

In tests with the *Cc* pair of genes, which affect aleurone color, a significant difference in heat tolerance was obtained using percentage of leaf injury as a criterion. The *C* factor entered the cross with the resistant parent. The results were barely significant (odds 19 to 1), and it may have been that only a fortuitous choice of material was responsible for the observed difference. The difference in survival, however, is considerably in favor of the *C* factor. One of the more striking differences occurring in this pair of genes is illustrated in Fig. 4.

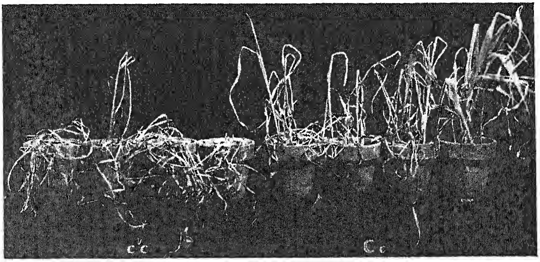

FIG. 4.—Segregates from a backcross showing differential response to controlled high temperatures of seedlings from colorless (*c c*) and colored (*C c*) kernels due to the *C c* pair of genes. The dominant *C* factor came from the heat-resistant parent in the original cross.

The short distance on the chromosome map between the loci for *Cc* and *Shsh* makes it difficult to explain on a basis of simple linkage relationships why heat tolerance was associated only with the *Cc* pair. Possibly an unknown gene for heat tolerance in the ninth linkage group may have been involved in one cross and not in the other. Another possibility is that the *Cc* factor pair itself might have some direct influence on heat tolerance.

SUMMARY

Inheritance of tolerance to heat and drought was studied in selfed lines of corn and crosses among them. Heat tolerance was definitely inherited and, in most of the cases studied, was intermediate to dominant. Hybrid vigor, in itself, apparently does not make a cross resistant to heat, at least in the seedling stage.

Linkage relations were studied between one or more factors in 8 of the 10 linkage groups and the possible factors determining heat tolerance. Close associations of heat tolerance with the Su_1su_1 and *Prpr* and a possible association with *Cc* loci were observed. The effects of gl_1 and gl_2 in the seedling stage apparently protect the corn seedlings

from injury by artificial heat, while the factor gl_3 probably does not possess this protective quality.

The *su* gene is considered to be directly responsible for susceptibility to heat injury as shown by the behavior of seedlings from sugary and starchy kernels. The equal distribution of the semi-sterile and normal plants among those tolerant to heat from a backcross involving chromosome 4 strengthens this belief.

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NOTES

THE USE OF PUNCHED CARD EQUIPMENT IN PREDICTING THE PERFORMANCE OF CORN DOUBLE CROSSES[1]

IN 1934, Jenkins[2] presented data comparing four methods of predicting the performance of double-crossed corn hybrids. Since that time his method B, which utilizes information on the four non-parental single-crosses, has been verified by several investigators and found quite satisfactory. This method is now used widely, but the labor involved in assembling and averaging the results from extensive single-cross tests without the aid of punched card equipment has proved a considerable task.

The corn breeding project at Ames, Iowa, has made extensive use of punched card equipment in the tabulation of yields, sums of squares, etc., for the past several years. Using the punched card equipment available in the Statistical Laboratory of the Iowa State College, the following method of predicting double-cross performance has been found quite satisfactory and much more rapid than hand tabulation.

The single-crosses involved in any particular test were written down in systematic order, as follows: First the six singles which can be produced from four inbreds, then the four additional singles which can be made when the fifth inbred line is added, etc. After this process was completed the single-crosses were numbered consecutively. The numbers are the single-cross code numbers used in sorting and tabulating.

The next step was a similar systematic listing of all possible double-crosses; first the three double-crosses which can be made among four inbred lines, then the 12 additional double crosses possible when a fifth line is added, etc. Using letters of the alphabet to designate inbred lines rather than actual pedigrees, pedigrees have been prepared for all possible combinations among 16 inbred lines. The listing of single-cross and double-cross combinations in the systematic order indicated permits the use of the same coded pedigrees for any set of single crosses involving all possible combinations of 16 or fewer lines. All possible single-cross combinations among 13 or 16 lines can be handled readily in 9×9 or 11×11 lattice square designs, respectively, which we have found to be quite satisfactory for corn yield comparisons.

After the key list of double-cross pedigrees was prepared the single-cross code numbers of the four non-parental single crosses were obtained from the systematically listed single crosses and recorded on the same sheet with the double-cross pedigrees, as illustrated below:

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[1]Journal Paper No. J-785 of the Iowa Agricultural Experiment Station, Ames, Iowa. Project No. 163. Contribution from the corn improvement program at Ames, Iowa, conducted by the Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture, in cooperation with the Farm Crops Subsection, Iowa Agricultural Experiment Station.

[2]JENKINS, M. T. Methods of estimating the performance of double-crosses in corn. Jour. Amer. Soc. Agron., 26:199–204. 1934.

Single-crosses	Double-crosses	Non-parental Singles
1 a × b	(a × b) (c × d)	2, 3, 4, 5
2 a × c	(a × c) (b × d)	1, 3, 4, 6
3 a × d	(a × d) (b × c)	1, 2, 5, 6
4 b × c		
5 b × d		
6 c × d		

When the calculations are completed for any single-cross test, the code numbers and the data for all variables used in prediction are punched on cards, one for each single-cross combination. Following verification these are run through the duplicator to obtain 10–20 cards for each cross. A total of 182 cards would be necessary for each single-cross combination if no resorting is to be done and the test involved all possible combinations of 16 lines. The cards are then sorted on the single-cross code numbers and laid out in consecutive order. One operator calls off the proper single-cross code numbers from the double-cross pedigree sheets and the second operator picks up the cards. A blank card is inserted after each set of four single crosses (one double cross). When the supply of cards of any one single-cross code number is exhausted, the assembled cards are placed in the tabulator and the data for each single cross and the totals for the sets of four crosses are listed. After the cards pass through this machine they are resorted and the assembling process continued until all possible double-cross combinations have been made. It is then a simple process to replace the double-cross code pedigree with the actual pedigree and to divide the totals of each set by four. These values then represent the predicted performance of the double cross for each of the variable studies. To simplify the procedure and reduce the labor involved, any lines consistently giving poor performance should be omitted before predictions are undertaken.

The use of punched card equipment merely provides an easy method of making a number of copies of the data for each single cross, of assembling the desired single crosses, and of obtaining the totals for each variable studied.

Where punched card equipment is not available the following procedure may be used advantageously: A number of copies of the single-cross data may be obtained by means of a mimeograph. These sheets may then be cut into strips, with the data for one single cross on each strip. The four single crosses involved in the prediction of each double cross can then readily be assembled and the prediction values determined. Either of these procedures will eliminate the necessity for repeated copying with all the labor and possibility of errors which such work involves.—AMY MILLANG AND G. F. SPRAGUE, *Iowa State College, Ames, Iowa.*

AN ELECTRICAL RESISTANCE METHOD FOR MAKING CONTINUOUS MEASUREMENT OF MOISTURE IN CONCRETE PAVEMENTS AND IN SOILS UNDER ROAD CONDITIONS

IN PREVIOUS communications,[1] an electrical resistance method was presented for making a continuous measurement of soil moisture under field conditions. The method made use of a plaster of paris block in which were imbedded two electrodes, and a special form of the Wheatstone bridge. The principle of the method was based upon the following facts:

1. The plaster of paris block takes up and gives up water very readily, so that it tends to maintain a close moisture equilibrium with its environment.
2. The electrical resistance of the plaster of paris block is inversely proportional to its water content, so that by calibration the electrical resistance becomes an index of moisture in soils or in concrete.
3. The comparatively high solubility of plaster of paris, which is 2,200 to 2,400 p.p.m., tends to act as a buffer and minimizes the influences of salts.
4. By imbedding the electrodes in a uniform and constant material such as plaster of paris, the uncertainties and errors which arise from differences in texture, composition, compaction, salt content, etc., of the medium surrounding the electrodes, are eliminated or greatly minimized, and the results thereby become more reliable and accurate.

The method as applied to soil has proved satisfactory. In the present note, it is the purpose to call attention to the possible application of the method to the measurement of moisture in concrete pavements under field conditions, and to other studies connected with concrete and soils.

It has been found that the method is capable of making a continuous measurement of moisture in concrete from the saturation point down to the air-dry condition, as the figures in Table 1 show.

TABLE 1.—*Relationship between electrical resistance and moisture content in concrete*

Resistance at 70° F, Ohms	Moisture, %
285	10.3 (saturated)
355	9.3
2,500	8.7
5,800	7.3
18,000	6.5
38,000	5.5
75,000	5.1
200,000	3.9
1,000,000	3.3 (air dry)

[1]Science, 89: 252. 1939. Mich. Agr. Exp. Sta. Tech. Bul. 172. 1940.

These results were obtained in the laboratory by casting around the plaster of paris block a shell of mortar ¼ inch thick. This mortar was made up by mixing in the following proportions by weight 50 parts of water, 100 parts Huron cement, and 200 parts of sand passing 2-mm sieve. After the mortar had been properly cured, it was allowed to dry at room temperature to different degrees of dryness, as indicated by the electrical resistance readings.

In order that the mortar shell might have a uniform moisture throughout its thickness, the entire block was wrapped in oiled paper and allowed to stand for 24 hours or longer. The resistance reading was then taken, the mortar shell broken off from the plaster of paris block, and its moisture determined by drying it at 100° C for 24 hours.

Other cells besides plaster of paris cells have been tried with the method, but the plaster of paris cells have proved to be the most satisfactory. The other cells tried consisted of fired clay, builder's cement, various concretes, cement and plaster of paris, marble dust with various binders, dental casting compounds, Keene's cement, and various commercial plasters (Alabatine, Alabastone, etc.).

Air-dry condition seems to be the lowest degree of moisture that the method is capable of measuring. The moisture content at the air-dry condition may vary somewhat, depending upon the variation in temperature and humidity, as well as upon composition of the mortar.

It would seem that a part of the moisture contained in concrete in the air-dry condition is water which is probably held with great chemical or physical forces and can only be determined by expelling it at high temperatures.

In order to measure such low moisture contents in concrete and in soils, a special electrical bridge has been developed which can be used to read very high resistances. This bridge is portable and weighs about 15 pounds. A vacuum tube oscillator, powdered by dry cell batteries, supplies alternating current at high frequency, eliminating polarization and electrolysis errors. The capacitance introduced by the plaster of paris block is balanced out by a variable condenser.

Besides measuring moisture, this electrical resistance method can also be used to ascertain whether or not the concrete or the soil is frozen. It has been found that when the water freezes the resistance jumps from about 500 ohms to about 50,000 ohms.

From all tests thus far made it seems that the method is satisfactory in making a continuous moisture measurement of soils and of concrete pavements at any depth under field conditions.

A detailed report of laboratory and field study of the method will be made by the Research Division of the Michigan Highway Department.—GEORGE BOUYOUCOS, *Soils Section, Michigan State College, East Lansing, Mich.*

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ORGANIC CARBON, pH, AND AGGREGATION OF THE SOIL OF THE MORROW PLATS AS AFFECTED BY TYPE OF CROPPING AND MANURIAL ADDITION[1]

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THE physical condition of soils under cultivation undergoes various changes, the nature and extent of which seem to depend largely upon the system of cropping and management practiced. The study here reported of the soil of the Morrow plats was concerned with the aggregation and organic carbon of this soil, particularly in relation to the results of a previous study by Stauffer (8).[3]

A review of the factors affecting soil structure has been published by Russel (7), and numerous recent investigators have dealt with changes in the porosity, organic matter content, and permeability of soils.

Browning (1), using the wet-sieving method of analysis, found that organic matter when added to soils of relatively poor structure increased the number of the larger sized aggregates. Bluegrass sod contained a much higher percentage of coarse aggregates than cultivated land. He reported, however, that the organic-matter content of some soils was considerably increased without increasing aggregation markedly, although the infiltration and percolation rates of these soils were usually increased.

Puhr and Olson (6), after using both the wet-sieving and the hydrometer methods of aggregate analysis on several South Dakota soils, concluded that cultivation had not had a pronounced effect on soil structure, even though it had caused a loss of 42% of the original organic matter.

Metzger and Hide (5) found with Kansas soil that different crops has measurably different effects on aggregation, and that the more aggregated portions of the soil contained significantly more organic carbon than the less aggregated portions.

[1]Contribution from the Division of Soil Physics, Department of Agronomy, Illinois Agricultural Experiment Station, Urbana, Ill. Published with the approval of the Director of the Illinois Agricultural Experiment Station. Received for publication June 27, 1940.

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[3]Figures in parentheses refer to "Literature Cited", p. 831.

THE MORROW PLATS AND THE PLAN OF THE INVESTIGATION

The Morrow plats, established at the Illinois Agricultural Experiment Station in 1876, have had the present cropping system since 1904. The plats are 2 rods wide and 4 rods long with ½ rod borders cropped like the adjacent plats between them. Fig. 1 shows a diagram of the six plats studied and gives the symbols or abbreviations to be used in this article in referring to the plats. The word "Sod" will refer to the grassed area surrounding the entire system of plats.

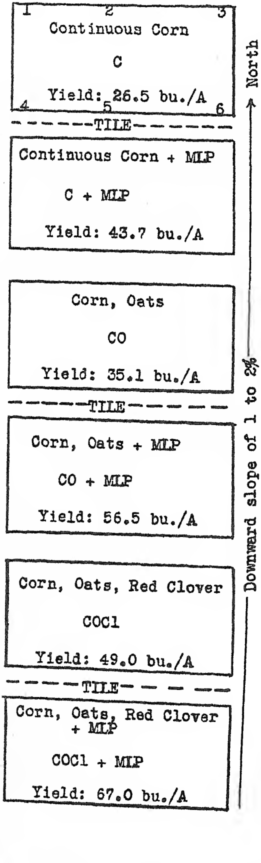

FIG. 1.—Diagram of Morrow plats, showing cropping systems, soil treatment, and corresponding symbols: slope, tile lines, average yields for the eight seasons since 1893 when corn was grown on all plats at the same time, and, in the C plat, the six sampling locations.

No fertilizers were used on these plats until 1904. Two tons of manure were applied per acre per year to the fertilized (MLP) plats from 1904 to 1909, and, since then, a weight of manure equal to the air-dry weight of the crops removed has been applied annually. In 1904, 1,704 pounds of limestone were applied per acre to the MLP plats and 5 tons more in 1919. Rock phosphate was applied per acre to the MLP plats as follows: 600 pounds yearly from 1904 to 1918, 3,000 pounds in 1919, and 200 pounds from 1920 to 1925. Further information on these plats is given by DeTurk, Bauer, and Smith (3) and by annual bulletins of the Illinois Agricultural Experiment Station.

The soil of the plats, a prairie type, was formerly called Carrington silt loam (8), but the drift underlying these plats is found at greater depths and is not leached as deeply as that usually found under the Carrington soils, so that name is no longer used. Some outwash may have been mixed with the loessial parent material on these plats.

Samples were taken on the plats before plowing in the spring of 1938 at uniformly measured distances from the ends and sides of each plat at six locations (Fig. 1). All plats had been in corn in 1937. The sod border had been in sod

since 1904. The sod border was sampled at a distance of 2 to 3 feet from the west end of each plat. At each location the soil was sampled at arbitrary depths of 0 to 6, 6 to 9, 9 to 13, and 13 to 18 inches, and each sample was stored and analyzed individually. For the 0 to 6 and 6 to 9 inch depths a 3-inch volume-weight cylinder was driven slowly into the soil to determine volume weights and to secure samples at the same time. For the other two depths a 2½-inch auger of the post-hole type was used. An auger even of this type is not desirable for taking samples for aggregate analysis, but it was necessary in this case to minimize the possible damage to the plats. It was originally intended to limit the study to the A horizon. This was not done, however, since the A horizon was more shallow than expected on the C and C plus MLP plats, as will be mentioned later in this article.

The samples were air dried and stored in glass fruit jars. After thorough mixing, each individual sample was analyzed for carbon, pH, and aggregation. The pH was determined on each sample by means of a glass electrode, using a mixture of 4 grams of soil and 2.4 cc of distilled water. Total carbon determinations were made by the method of Winters and Wimer (10) and mechanical analyses by a method similar to that of Winters and Harland (11). The samples from two locations on each plat were analyzed mechanically, with the exception of the COCl plat in which case the samples from all six sampling locations were analyzed.

Aggregate analyses were made by a wet-sieving method similar to that described by Yoder (12). Wet-sieving is not dependent on the settling velocities of the aggregates and so has advantages over other methods of aggregate analysis (12). The results of aggregate analyses depend to a considerable extent upon the pretreatment of the samples (1, 12) and even upon the time of year the samples are taken (1, 4, 7).

Three sizes of sieves were used, *viz.*, Nos. 35, 60, and 140, with nominal openings of 0.50, 0.25, and 0.10 mm, respectively. A fourth fraction, 0.10 to 0.05 mm in diameter, was obtained by sedimentation in beakers. The time of settling was taken as 40 seconds for a depth of 10 cm. No adjustment for varying water temperature, which was approximately 20° to 22° C, was made because of the uncertainties in calculating the rate of aggregate sedimentation (12). The National Bureau of Standards' specifications for "standard" sieves allow the following tolerances for Nos. 35, 60, and 140: For the maximum opening 25, 40, and 60%, and for the average opening 5, 6, and 8%, respectively. In this investigation, all the No. 35 sieves used had been made with the intention of meeting the National Bureau of Standards' specifications, as were the No. 60 sieves used on the samples from the 0 to 6 and 6 to 9 inch soil depths. "Routine" or "general purpose" sieves were used for the No. 140 on all samples and for the No. 60 on the 9 to 13 and 13 to 18 inch depths. One large supply house estimated the tolerances of such sieves to be about twice those of the "standard" grade, which are considerably more expensive, and, though desirable, are probably not necessary.

The machine used to raise and lower the sieves consisted of an electric motor and suitable shafts and pulleys mounted on a table. It raised and lowered six nests of three sieves each through a distance of 1¼ inches 25 times a minute (50 oscillations or single movements per minute) for a period of 30 minutes. The sieves were set in such a way that at the bottom of the down stroke the upper rim of the top sieve was just above the surface of the water. The rate of 25 upward movements per minute was sufficiently slow to allow 1¼ inches of water to drain through the sieves each time, and yet it was probably not fast enough to produce any undesirable dispersion; in fact, the larger aggregates resting on the top sieve were not raised off the wire cloth by the force of the water during the down stroke.

There was no indication during the determinations that the variation in temperature (about 4° C from the average) of the distilled water used affected the results.

All aggregate analyses were made in duplicate and the agreement found between duplicates was generally good. When any two fractions of the duplicates varied more than 10% from the average of the two, the analysis was repeated and the average of the triplicates taken as final. Of the 168 samples analyzed in this investigation, only 18 had to be re-analyzed to meet the above requirement. The aggregates were dried at 105° C and the percentages of the various sized aggregates were calculated to the nearest tenth of 1% on the basis of the amount of oven-dry soil used for analysis (about 25 grams). From this percentage of aggregates of any given size was subtracted the percentage of sand of that size in the soil as determined by mechanical analysis. Hence the aggregates reported in Tables 5 and 6 include no sand particles of equal or greater size, and the percentages of aggregates are minimum values. Some of the fine sand, for instance, undoubtedly occurred in aggregates of medium sand size, but the entire percentage of fine sand was nevertheless subtracted from the weight of sand and aggregates of fine sand size.

RESULTS AND DISCUSSION

TEXTURE

The mechanical analyses (Table 1) show that the soil of these plats is very uniform in average physical composition. On the COCl plat, however, the samples from location 1 were markedly higher in sand than samples from the other plats or even than other samples from the same plat. On this particular plat, therefore, mechanical analyses were made of the samples from each of the six sampling locations, and the results for this plat, given in Table 1, are averages of six determinations. The percentages of total sands from samples 1 and 6 on the COCl plat were, in the 0 to 6 inch depth, 11.1 and 4.9; the 6 to 9 inch depth, 14.7 and 4.1; in the 9 to 13 inch depth, 18.7 and 2.9; and in the 13 to 18 inch depth, 23.2 and 2.8, respectively. The subsoil, deeper than 18 inches, at location 1 was also more sandy than the subsoils at the other locations. Such variation is not uncommon in this morainal region and serves to emphasize the importance of care in sampling soils.

pH VALUES

The pH of the soil of plats treated with ground limestone at the rate of 1,705 pounds per acre in 1904 and 5 tons in 1919 was higher than that of unlimed plats in the 0 to 6 and the 6 to 9 inch depths (Table 2, Fig. 2). In the upper 9 inches, the arithmetical average of the pH ranged from 4.81 to 5.36 in the unlimed plats and from 5.52 to 6.20 in the limed plats. The average pH of the soil below 9 inches ranged from 5.35 to 5.87 and showed no material change due to liming. However, the high value of 5.87 for 6 determinations in the 9 to 13 inch depth on the CO plus MLP plat indicated that liming may have had some effect to a depth of 13 inches on this particular plat.

TABLE 1.—*Mechanical analyses of the soil of the Morrow plats, percentage by weight of oven-dry soil.**

Plat	>0.5 mm†	0.5–0.25 mm	0.25–0.10 mm	0.10–0.05 mm	Total sands, 2.0–0.05 mm	Clay <0.002 mm	Silt, 0.05–0.002 mm (by difference)
			0 to 6 Inch Depth				
C	2.1	2.0	1.3	1.8	6.9	24.7	68.4
C+MLP	1.7	1.7	1.1	1.6	5.8	24.8	69.4
CO	2.2	1.6	1.1	1.6	6.4	25.6	68.0
CO+MLP	2.3	2.2	1.9	1.5	7.8	25.7	66.5
COCl	2.0	1.9	2.2	1.9	7.8	25.6	66.6
COCl+MLP	1.7	1.7	1.1	1.6	6.0	25.0	69.0
			6 to 9 Inch Depth				
C	2.0	1.6	1.0	1.4	5.3	26.6	68.1
C+MLP	2.3	1.3	0.9	1.3	5.3	26.4	68.3
CO	1.6	1.5	0.9	1.2	5.0	27.3	67.7
CO+MLP	2.3	1.8	1.4	1.3	6.4	26.2	67.4
COCl	1.5	1.9	2.1	1.5	7.0	26.2	66.8
COCl+MLP	1.3	1.6	1.0	1.3	5.0	26.9	68.1
			9 to 13 Inch Depth				
C	1.5	1.2	0.8	1.2	4.4	28.6	67.0
C+MLP	1.4	1.4	0.8	1.2	4.6	28.2	67.2
CO	1.4	1.3	0.8	1.0	4.5	27.0	68.5
CO+MLP	1.8	2.2	1.3	1.4	6.0	25.3	68.7
COCl	1.6	2.0	2.1	1.5	7.1	27.0	65.9
COCl+MLP	1.0	1.3	0.8	1.0	4.0	28.6	67.4
			13 to 18 Inch Depth				
C	1.3	1.2	0.7	1.1	3.7	31.7	64.6
C+MLP	1.0	1.2	0.8	1.1	4.0	31.1	64.9
CO	1.7	1.2	0.8	1.2	4.3	29.1	66.6
CO+MLP	1.7	2.1	1.4	1.6	6.7	26.3	67.0
COCl	1.8	2.3	2.5	1.6	8.0	28.4	63.6
COCl+MLP	1.0	1.3	0.9	1.0	4.0	26.3	69.7

*Averages of two samples per plat except for COCl plat in which six samples were analyzed and averaged. The letters C, O, and Cl signify corn, oats, and clover, respectively, and MLP the soil treatment of manure, lime, and rock phosphate.

†Includes a small amount of material larger than 2 mm in diameter.

TABLE 2.—*Average pH and range in pH of six samples from each of four depths on each of the Morrow plats.**

Plat	0–6 inch		6–9 inch		9–13 inch		13–18 inch	
	Average	Range	Average	Range	Average	Range	Average	Range
C	4.81	4.96–4.53	5.36	5.70–4.97	5.63	5.91–5.40	5.79	6.17–5.38
C+MLP	5.54	5.82–5.20	5.69	5.89–5.49	5.70	6.00–5.43	5.71	5.94–5.46
CO	4.99	5.02–4.93	5.26	5.50–5.11	5.52	5.78–5.41	5.63	5.89–5.42
CO+MLP	5.52	6.00–5.16	5.82	6.27–5.47	5.87	6.60–5.50	5.85	6.60–5.58
COCl	4.89	4.92–4.80	5.16	5.28–4.99	5.35	5.58–5.20	5.47	5.70–5.37
COCl+MLP	6.20	7.05–5.40	6.19	7.01–5.47	5.48	5.69–5.30	5.48	5.78–5.23

*In calculating the averages, the pH values were treated simply as if they were arithmetical numbers.

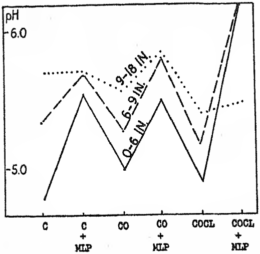

FIG. 2.—Effect of crops and soil treatment on the pH of the soil of the Morrow plats.

The pH of all plats reached a maximum in the 9 to 13 or 13 to 18 inch depths except for the COCl plus MLP plat which had its maximum in the upper 6 inches.

VOLUME WEIGHT

The fertilizers and crops used on these plats had little, if any, effect on the volume weight of the soil as measured with a metal cylinder (Table 3). Fertilization and the longer rotations appear to have decreased the volume weight slightly but consistently in the 0 to 6 inch layer, but the differences are not significant statistically.

TABLE 3.—*Average volume weight and range in volume weight of six samples from each of two depths on each of the Morrow plats and the adjoining sod.*

Plat	0–6 inch		6–9 inch	
	Average	Range	Average	Range
C	1.37	1.42–1.33	1.25	1.30–1.19
C+MLP	1.31	1.34–1.27	1.26	1.40–1.07
CO	1.33	1.38–1.28	1.30	1.36–1.22
CO+MLP	1.24	1.35–1.16	1.37	1.46–1.29
COCl	1.31	1.40–1.25	1.28	1.40–1.12
COCl+MLP	1.21	1.29–1.12	1.29	1.34–1.23
SOD	1.28	1.39–1.23	1.29	1.40–1.17

SOIL CARBON

The total carbon content of the samples, given in Table 4 and Fig. 3, is practically equivalent to the organic carbon because the inorganic carbon is negligible in amount. Only 1 of 29 samples from various depths between 0 and 18 inches had an inorganic carbon content as high as 0.01%.

The organic matter content in the upper 9 inches was maintained at a markedly high level only by the best treatment, namely, a corn-oats-clover rotation plus applications of manure, lime, and phosphate, and it was at a markedly low level only in the plat having the poorest treatment, namely, continuous corn without fertilizers. This low level under continuous corn was due, to some extent at least, to erosion, as will be discussed further in this article. The bluegrass in the sod border, undisturbed for 34 years, was no more effective than the fertilized corn-oats-clover rotation in maintaining the total carbon content of the soil (Table 4). Below 9 inches neither rotation nor soil treatment had much effect on the organic content of the soil.

TABLE 4.—*Average carbon content and range in carbon content in six samples from each of four depths on each of the Morrow plats and the adjoining sod.*

Plat	0–6 inch, %		6–9 inch, %		9–13 inch, %		13–18 inch, %	
	Average	Range	Average	Range	Average	Range	Average	Range
C	1.74	1.82–1.66	1.71	2.01–1.29	1.48	1.88–0.91	1.11	1.51–0.69
C+MLP	2.09	2.22–1.95	2.15	2.41–2.01	1.91	2.11–1.58	1.44	1.71–1.09
CO	2.14	2.18–2.09	2.16	2.31–2.05	2.04	2.39–1.80	1.70	2.14–1.40
CO+MLP	2.44	2.74–2.22	2.29	2.46–2.09	2.02	2.25–1.83	1.67	1.86–1.48
COCl	2.28	2.72–1.96	2.34	2.76–1.98	1.99	2.57–1.64	1.69	2.17–1.32
COCl+MLP	3.35	4.06–2.79	2.92	3.88–2.14	2.18	2.69–1.71	1.77	2.42–1.37
Sod	3.20	3.55–2.91	2.16	2.35–1.89	2.16	2.31–1.86	1.94	2.12–1.66

An analysis of variance showed that differences in total carbon produced by the fertilizer treatment and by the rotations are significant (1% level), and also that the depths differed in total carbon content. It also showed that the fertilizer treatment produced significantly (1% level) different results with the different rotations, and also different results in the 0 to 9 as compared with the 9 to 18 inch depths. The rotations also differed in their effects on these depths.

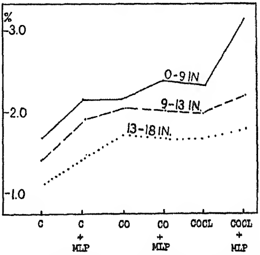

FIG. 3.—Effect of crops and soil treatment on the total carbon in the soil of the Morrow plats.

The above effects of the fertilizer treatment and rotations were analyzed statistically in more detail, and the results are summarized in Tables 5, 6, and 7. The following points are worthy of mention:

(a) The manure-lime-phosphate treatment maintained at a higher level the total carbon content of the soil above 9 inches, but it had little or no effect below 9 inches (Table 5). The difference ranged from about 1% in the 0 to 6 inch depth under corn-oats-clover to 0 below 9 inches under corn-oats.

(b) The higher total carbon content maintained by fertilizer treatment over no fertilizer was more pronounced at all depths with continuous corn and with corn-oats-clover than it was with the corn-oats rotation.

(c) The unfertilized corn-oats and corn-oats-clover rotations maintained at a significantly higher level the total carbon at all depths as compared with continuous corn. The observed amount of this increase was about 0.5% of carbon (Table 6). The unfertilized corn-oats-clover rotation was not significantly better than the corn-oats-rotation in maintaining the carbon content of the soil.

TABLE 5.—*Increase or decrease in percentage of total soil carbon produced by manure-lime-phosphate treatment on the Morrow plats under three rotations and at four depths.*

Depth, inches	Corn continuously		Corn-oats rotation		Corn-oats-clover rotation	
	Observed mean increase (6 samples), % of sample weight	True value lies between*	Observed mean increase or decrease (6 samples), % of sample weight	True value lies between*	Observed mean increase (6 samples), % of sample weight	True value lies between*
0–6	0.35	0.02 and 0.68	0.30	−0.03 and 0.63	1.07	0.74 and 1.40
6–9	0.44	0.11 and 0.77	0.13	−0.20 and 0.46	0.58	0.25 and 0.91
9–13	0.43	0.10 and 0.76	−0.02	−0.35 and 0.31	0.19	−0.14 and 0.52
13–18	0.33	0 and 0.66	−0.03	−0.36 and 0.30	0.08	−0.25 and 0.41

*Obtained from the inequality $d - t_{.05}s < ς < d + t_{.05}s$, where d is the observed difference, ς the true difference, s and estimate of the "error variance" derived from the 120 degrees of freedom obtained from comparisons between the six samples within groups, and $t_{.05}$ is the 5% significance level of "Student's" t for 120 degrees of freedom. There is 1 chance in 20 that the true value for the difference produced by treatment lies outside the range given.

TABLE 6.—*Increase or decrease in percentage of total soil carbon produced at four depths by unfertilized rotations on the Morrow plats.*

Depth, inches	Corn-oats versus corn		Corn-oats-clover versus corn		Corn-oats-clover versus corn-oats	
	Observed mean increase (6 samples), % of sample weight	True value lies between*	Observed mean increase (6 samples), % of sample weight	True value lies between*	Observed mean increase or decrease (6 samples), % of sample weight	True value lies between*
0–6	0.40	0.07 and 0.73	0.54	0.21 and 0.87	0.14	−0.19 and 0.47
6–9	0.45	0.12 and 0.78	0.63	0.30 and 0.96	0.18	−0.15 and 0.51
9–13	0.56	0.23 and 0.89	0.51	0.18 and 0.84	−0.05	−0.38 and 0.28
13–18	0.59	0.26 and 0.92	0.58	0.25 and 0.91	−0.01	−0.34 and 0.32

*See footnote to Table 5. There is 1 chance in 20 that the true value for the difference produced by the rotations lies outside the range given.

(d) With the fertilized rotations, continuous corn was about equal to the corn-oats rotation in maintaining the total carbon content of the soil at all depths. The corn-oats-clover rotation was much better in this respect than corn or corn-oats, for it maintained total carbon

from 0.6 to 1.26% higher than the other two rotations in the upper 9 inches of soil (Table 7).

TABLE 7.—*Increase or decrease in percentage of total soil carbon produced at four depths by fertilized rotations on the Morrow plats.*

Depth, inches	Corn-oats versus corn		Corn-oats-clover versus corn		Corn-oats-clover versus corn-oats	
	Observed mean increase (6 samples), % of sample weight	True value lies between*	Observed mean increase (6 samples), % of sample weight	True value lies between*	Observed mean increase (6 samples), % of sample weight	True value lies between*
0– 6	0.35	0.02 and 0.68	1.26	0.93 and 1.59	0.91	0.58 and 1.24
6– 9	0.14	−0.19 and 0.47	0.77	0.44 and 1.01	0.63	0.30 and 0.96
9–13	0.11	−0.22 and 0.44	0.27	−0.06 and 0.60	0.16	−0.17 and 0.49
13–18	0.23	−0.10 and 0.56	0.33	0 and 0.66	0.10	−0.23 and 0.43

*See footnote to Table 5.

(e) In the maintenance of total carbon in the 9 to 18 inch depth, there was no significant difference between the three rotations whether fertilized or unfertilized, with the exception of unfertilized, continuous corn which was clearly inferior (Tables 6 and 7).

(f) The total carbon content of the soil usually decreased as the depth increased, the decrease being more rapid at successively greater depths. The differences in total carbon between the 0 to 6, 6 to 9, and 9 to 13 inch depths were not significant except in the fertilized corn-oats-clover plat. The 13 to 18 inch layers averaged 0.37% of the total carbon and were very uniform in all plats.

(g) The average increase observed in total carbon resulting from soil treatment, including all depths and rotations, was 0.323, and, if it is asserted that the true value lies between 0.323 ± 0.165, there is a 1 in 20 chance that this assertion is false. The average content of total carbon of these plats was 1.70% with continuous corn, 2.06% with corn-oats, and 2.31% with the corn-oats-clover rotation. The average content at the various depths was 0 to 6 inches, 2.34%; 6 to 9 inches, 2.26%; 9 to 13 inches, 1.94%; and 13 to 18 inches, 1.56%.

The above results show that for maintaining soil organic matter continuous corn was inferior to corn-oats when no soil treatment was used. With manure, lime, and rock phosphate, however, the continuous corn was practically equal to the corn-oats rotation.

The unfertilized corn-oats-clover rotation had no advantage in organic matter maintenance over corn-oats, but the fertilized corn-oats-clover rotation was much better than the five other combinations of rotation and treatment studied, and appeared to be better

even than bluegrass sod undisturbed for 34 years. This indicates that good management of cultivated soil may be fully as effective in the maintenance of organic matter as a continuous sod crop.

AGGREGATION

Aggregate analyses showed that grass increased the amount of large aggregates greatly (600% over corn or corn-oats) in the upper 6 inches but not below this depth (Tables 8 and 9). Only the best cropping system, namely, corn-oats-clover rotation plus manure, lime, and rock phosphate, was effective in materially increasing the amount of large aggregates in the upper 6 inches of the soil. This fertilizer treatment appeared to increase slightly the amount of aggregates below 0.25 mm in diameter with any cropping system.

TABLE 8.—*Average percentage and range in the percentage of aggregates in six samples from each of the Morrow plats and the adjoining sod at the 0 to 6 inch depth.*

Plat	>0.5 mm	Range	0.5–0.25 mm	Range	0.25–0.10 mm	Range	0.10–0.05 mm	Range
C	8.0	14.5– 4.0	8.2	11.3– 5.9	16.0	18.0–14.2	22.3	25.6–19.1
C+ MLP	6.2	7.4– 4.9	8.1	9.4– 7.1	18.0	20.1–16.1	23.9	27.0–20.9
CO	5.7	7.6– 2.9	6.4	6.8– 6.2	13.7	14.0–12.3	23.5	25.6–20.8
CO+ MLP	7.4	11.5– 4.0	8.1	9.8– 7.4	16.8	18.6–15.9	24.5	26.5–22.9
COCl	11.0	13.1– 9.1	8.4	9.6– 7.1	15.3	16.7–14.4	21.9	22.9–19.0
COCl+ MLP	13.2	18.3– 9.6	13.3	15.1–12.0	20.1	21.0–18.8	19.1	21.9–15.3
Sod	50.0	63.4–44.5	16.9	21.2–12.3	11.9	14.6– 6.7	3.5	4.9– 1.8

TABLE 9.—*Average percentage of aggregates in six samples from each of three depths on each of the Morrow plats and the adjoining sod.*

Plat	6 to 9-inch depth				9 to 13-inch depth				13 to 18-inch depth			
	0.5 mm	0.5–0.25 mm	0.25–0.10 mm	0.10–0.05 mm	0.5 mm	0.5–0.25 mm	0.25–0.10 mm	0.10–0.05 mm	0.5 mm	0.5–0.25 mm	0.25–0.10 mm	0.10–0.05 mm
C	35.4	15.6	13.9	11.2	34.6	22.3	18.2	8.4	44.5	20.0	15.8	6.1
C+ MLP	20.5	14.5	17.4	16.7	23.6	21.8	21.8	12.6	35.3	21.9	18.8	8.2
CO	24.4	14.6	16.2	16.3	26.4	20.2	20.9	11.7	33.1	21.4	18.7	8.8
CO+ MLP	22.8	16.5	17.7	15.3	19.5	21.5	23.4	12.4	25.9	23.0	22.0	9.8
COCl	38.4	15.1	13.3	10.2	26.3	20.6	20.5	10.2	28.6	20.5	19.7	10.2
COCl+ MLP	20.6	17.5	20.2	16.6	20.4	22.6	23.1	13.7	27.3	23.0	21.7	11.1
Sod	26.9	20.7	19.1	10.2	20.0	18.5	20.7	12.2	24.6	19.7	20.9	10.8

The 6 to 9 inch layer showed little or no difference in aggregation in the C plus MLP, CO, and CO plus MLP plats. The C, COCl, and COCl plus MLP plats were higher in total aggregation than the

other three plats, the C and COCl plats having a high percentage of coarse aggregates. In the lower two depths, namely, 9 to 13 inches and 13 to 18 inches, the continuous corn plat was highest in the largest aggregates (above 0.5 mm in diameter), and also in total aggregation. This is apparently due to the fact that much of the surface soil on this plat has been removed by erosion.

The results show that comparatively large differences in organic matter content may exist without a proportional effect on aggregation or volume weight. Thus, the COCl plus MLP plat in the 0 to 6 inch depth was almost 50% higher than the COCl plat in total carbon, but the differences in aggregation were comparatively minor. This agrees with the findings of Browning (1) and of Puhr and Olson (6). Further, in the 0 to 6 inch depth, the sod border was no higher in total carbon but very much higher in aggregation than the COCl plus MLP plats.

EROSION

The plats growing corn annually were poorly aggregated in the surface but showed increasing amounts of large aggregates with depth. This increase in aggregation with depth is apparently due, however, not to the corn but to erosion which has brought the B horizon 6 to 9 inches nearer the surface under these plats. When this work was begun, it was assumed that little or no soil had been lost from these plats by erosion because of the slight slope (1 to 2%) high organic matter content, and high permeability. In a previous study, Stauffer (9) found that No. 15, a soil similar to this, had an average infiltration of 3.7 inches of water in 1 hour. The occurrence of considerable sheet erosion was later demonstrated, however. The color and appearance of the samples from the continuous corn plats at depths below 9 inches; their comparatively large variations in pH, total carbon, and aggregation; and their high pH values and low carbon content all indicated admixture with materials from the B horizon. Samples from depths of 18 to 30 inches under the COCl and COCl plus MLP plats were similar in aggregation to those below 12 inches under the continuous corn plats.

Careful borings made in the continuous corn plat, unfertilized, showed a transition from the A to the B horizon at approximately 13 inches. In the COCl plus MLP plat, and in the grass border, this transition occurred at 19 to 20 inches. The plats located between the C and COCl plus MLP plats showed a gradual increase in depth from the former to the latter.

A small amount of sheet erosion annually on the continuous corn plats, which are not only kept in an intertilled crop but receive runoff from the other plats, has removed enough soil to bring the B horizon into the 13 to 18 inch zone. This would require the removal of about 6 inches of soil or only 1/10 inch annually since the plats were established, without considering any previous cropping that may have been carried on. The extent of sheet erosion on land of such a slight slope and high degree of permeability is not generally appreciated; nevertheless, losses similar to those estimated above were also found by Conrey and Burrage (2) on Ohio plats of similar slope and good physical condition.

The erosion on the continuous corn plats makes it difficult to compare the soil of these plats with that of the others, particularly at the greater depths where one may be dealing with the B horizon under continuous corn and with the A horizon under the other crops. Thus, a comparatively low content of organic matter in the lower layers of the corn plats may not be due entirely to the corn crop itself but to original differences between the A and B horizons.

PERCOLATION

The results of Stauffer (8) indicate that, on this soil, the percolation of water may be more sensitive to physical changes in the soil than any other measurement so far used. The increased percolation observed by Stauffer in the unfertilized plats at the lower depths is correlated with a large proportion of coarse aggregates in each case. In the plot growing corn continuously, the coarseness of the aggregates is probably due to mixture with the B horizon as discussed above, while in the corn-oats-clover plat, the rotation appears to produce coarse aggregates when manure, lime, and phosphate are not used. In addition, the soil in a part of the corn-oats-clover plat is more sandy than that of any other part of the six plats studied.

SOIL VARIATION

In this investigation each sample from six locations on each plat and from each of four depths was analyzed individually. The variability found in these 1/20 acre plats emphasized the importance of multiple or composite sampling, even on the plats where erosion was least serious (Tables 1 to 5). Although these plats are small and have been carefully handled, considerable variation in pH and total carbon exists in the plow layer of the north and south halves of the fertilized plats (Table 10).

TABLE 10.—*Average pH and total carbon of the three 0 to 6-inch samples taken from the north and from the soil halves of the fertilized plats.*

	C+MLP		CO+MLP		COCL+MLP	
	North	South	North	South	North	South
pH	5.35	5.73	5.80	5.50	5.50	6.88
Total carbon %	2.01	2.16	2.49	2.71	3.00	3.71

It will be noted that the south, or higher half, is more acid in the COCl plus MLP and C plus MLP plats but lower in the CO plus MLP plat, while the total carbon content increases from the lower (north) to the higher (south) sides of each plat. The unfertilized plats not only show no significant variation in the pH of the plow layer, but also practically no variation in total carbon, i.e., 0.07% of the C plat, 0.03% in the CO plat, and 0.25% in the COCl plat, all in favor of the higher (south) half.

SUMMARY

An investigation of the mechanical analysis, volume weight, pH, total carbon, and aggregate analysis of the soil of the Morrow plats was carried out. These plats, established in 1876 and cut down to 1/20 acre in 1904, have been subjected since 1904 to three different cropping systems, namely, continuous corn, a corn-oats rotation, and a corn-oats-clover rotation, with and without manure, lime, and rock phosphate. Samples were taken from each of six locations on each plat and from four depths at each location to 18 inches, and were analyzed individually.

The plats were remarkably uniform in mechanical composition to a depth of 18 inches, with the exception of one location as noted, and fairly uniform in volume weight to a depth of 9 inches.

The limed plats were considerably higher in pH than unlimed plats from 0 to 9 inches but not so much below 9 inches.

The unfertilized continuous corn plat was lowest in total carbon to a depth of 13 inches, whereas the fertilized corn-oats-clover plat was highest to 9 inches. The fertilizer treatment was more effective in lessening the decrease of the carbon content of the soil with continuous corn and corn-oats-clover than with corn-oats. The fertilized corn-oats rotation was not materially better in maintaining organic matter than fertilized continuous corn. The sod border, in bluegrass continuously for 34 years, was no higher in total carbon than the fertilized corn-oats-clover plat.

Grass in the border adjoining the plats exerted the most marked effect on aggregation in the upper 6 inches, with the fertilized corn-oats-clover rotation second.

The soil treatment and the rotations practiced, including continuous grass, even when continued for many years, had little effect on the pH, organic matter content, or aggregation of this soil below a depth of 9 inches.

Examination and analysis of the samples and borings in the field showed considerable erosion had occurred on the plats of lower elevation and on which corn was grown continuously.

Considerable variations in pH and total carbon were observed in the fertilized plats.

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THE MICROFLORA IN THE SOIL AND IN THE RUN-OFF FROM THE SOIL[1]

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PRESENT data indicate that large amounts of the finer particles of the soil are carried away in the water run-off. Literature is lacking on a comparison of the organisms in the soil from which the water came with those in the run-off from the soil. Information is not complete until a clear understanding of the effect which the erosion of the soil has on the micro-organic population is achieved.

Studies have shown that sheet erosion causes a loss primarily of the finer particles of soil which are carried away in the run-off. It is further known that many bacteria are adsorbed on the finer particles. This adsorption was emphasized by Dianowa and Woroshilowa (4)[3] and by Peele (10). Organisms other than bacteria may be affected similarly for Cutler (3) has shown that protozoa were removed from suspensions of soil.

Since most of the organic material is near the surface of the soil and since a large part of the micro-organic population is aerobic and near the surface, it should be suspected that the soil near the surface contains the largest number of the mixed population. Many workers (2) have shown that this condition actually exists. Therefore the conditions are ideal for the organisms to accompany the finer particles when they are carried away by the water. They may be lost either adsorbed with the soil particles or suspended in the run-off. The purpose of this paper, therefore, is to show the extent to which certain physiological groups of the micro-organic population are carried away in the run-off.

EXPERIMENTAL MATERIAL

The samples of soil and the run-off from the soil were collected at the U. S. Dept. of Agriculture Soil Conservation Experiment Station at the Arnot Forest near Ithaca, N. Y. The sampling was started in June 1935 and continued until November of the same year. Further work was resumed May 1, 1936, and suspended in September 1936. The plats are located on the Bath flaggy silt loam soil series, and have a slope of about 20%. Some are on virgin soil and some on soil that has been cultivated for about 70 years. In both cases, in addition to the controls, the plats have received mineral fertilizers and were in a rotation of oats and clover when the samples were collected. By taking samples of the soil of these plats and determining the microflora *in situ* it has been possible to compare the results with those obtained by making similar determinations in the run-off from such plats. In both cases the population is expressed as numbers in a gram of dry material. The samples of soil were analysed within 48 hours and the samples of the run-off within 24 hours. In most instances a much shorter time was required for each than that indicated. The samples consisted of an aliquot of the entire run-offs. They were obtained after stirring the entire quantities.

[1]Contribution from the Department of Agronomy, Cornell University, Ithaca, N. Y. Received for publication May 17, 1940.

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[3]Figures in parenthesis refer to "Literature Cited", p. 841.

All soils contain certain physiological groups that bring about important changes in the organic and inorganic constituents. No one group, however, appears any more important than any other. For this reason it was considered desirable to make quantitative determinations of several groups, especially of those which are likely to have the largest population. Among these are those that grow on soil-extract agar, ammonifiers, cellulose-decomposers, algae, azofiers, rhizobia and fungi.

The quantitative determinations of the total number of organisms as used in this work were made by counting all colonies that appeared on plates made of soil-extract agar, whereas the total number of fungi was made by counting all colonies resembling fungi that appeared on plates of peptone-glucose-acid agar. To make counts of all other organisms, the dilution method of Hiltner and Stormer (7) was employed. This consisted in taking portions of the soil or the run-off as the inoculum and adding them to a medium that was suitable for the growth of the particular organism in question. The smallest portion of the inoculum which gave growth was taken to represent the number of organisms in that fraction of a gram. From this the number in a gram could be calculated.

The formulae for cellulosic, algal, anaerobic, and agar-media were taken from the manual by Fred and Waksman (5). The aerobic-medium was modified, however, by the addition of a gram or so of sand and 0.25% $NaHSO_3$. The sand probably reduced the circulation of the liquid containing oxygen while the $NaHSO_3$ evidently lowered the oxidation-reduction potential.

The presence of ammonifiers, ammonia and sulfur oxidizers were detected by the presence of their end products, following the procedures described by Hansen (6), Wilson (11), and Brown (1), respectively. Nodule formation on the roots of red clover (*Trefolium frateuse*), alfalfa (*Medicago sativa*), and vetch (*Vicia villosa*) indicated the presence of their respective rhizobium. The culture tubes containing the anaerobic medium were incubated 14 days, then heated for 10 minutes to 80° C and some of the material transferred to a fresh tube containing a medium of similar composition. The presence of the organism was noted when gas was observed upon further incubation for a period of 5 days. The length of the incubation was varied to meet the growth requirements of the particular group of organisms. Cultures for the presence of algae were placed in light and the number of cellulose-destroying-organisms detected by their disintegrating action on strips of filter paper. Sulfanilic acid and alpha-napthyl-amine in acetic acid were used to detect the formation of nitrites from ammonia. Directions for these tests may be found in the manual by Fred and Waksman (5). Total solids in the run-offs were obtained by evaporating large volumes of the run-offs and weighing the residues.

PRESENTATION OF DATA

It is presumed that the micro-organic population found in the run-off from the soil came from the soil. No tests were made of the rainfall to show what kind or how many organisms it might have contained. Marshall (8) reports an average of only 3.5 in each ml. Micro-organisms in addition to the soil particles should be expected in the run-off, for the work of Peele (10) and others showed that many bacteria may be adsorbed on the particles of soil. In 1935 and 1936 many data were obtained bearing on the population in the soils of the various plats and in the run-offs from the soils. Since the findings are similar in many ways only those will be given in detail which illustrate the findings.

In Table 1 are given the results of 12 determinations of the micro-organic population which was obtained between June 17 and November 3. The table also shows the population in the run-offs after five rains. It is evident that for each gram of solid material there were many more organisms in the run-off than there were in the soil from which the run-off came. The numbers as determined by the agar plate method showed at no time more than 21 million in each gram of soil. In most cases it was less than one-half this number. The numbers in the run-off from this plat following five rains exceeded the numbers found in the soil in every instance. The average number as ascertained by six determinations before the rain was less than 5 million, and 5 days before the rain on August 13 the number was less than 10 million. In the run-off after 0.4 inch of rainfall on this date, however, there were 10,871 million. If the dilution counts of such groups of organisms as the ammonifiers, ammonium oxidizers, anaerobes, and those of other physiological groups are considered, the results are similar to the above although the numbers are much smaller.

The micro-organic population in the soil of a virgin, unfertilized plat and that in the run-off from the same plat are shown in Table 2. A larger number in the run-off is evident. It resembles that found in the run-off from the cultivated soil shown in Table 1, and the same type of comparisons between the population in the soil and in the run-off could be made.

Of equal interest are the summary results from the samples of soil and from the samples of the run-offs from the soil during the period of June 17 to November 3. During this period 12 determinations were made of the population in the soil of eight plats and 5 in the run-offs after rains. Plat A-5 was growing corn and had received 200 pounds of a 5–10–15 fertilizer annually. Plat A-6, also in corn, was unfertilized and A-8 was fallow. A-11 was cropped in a rotation of oats, clover, and corn with 300 pounds of superphosphate, 2,000 pounds of limestone before oats, 6 tons of manure, and 300 pounds of superphosphate before corn. E-1, in a rotation of oats, clover, and corn, was strip-cropped, and unfertilized. E-2, in a rotation of oats, clover, and corn, was unfertilized but cultivated up and down the slope. (See Table 4.) Plat E-3, in a rotation of oats, clover, and corn, was fertilized with 300 pounds of superphosphate, 2,000 pounds of limestone before oats, 6 tons of manure, and 300 pounds of superphosphate before corn.

The rainfall and the run-off, together with the quantity of solids in the run-off from June 8 to October 29, 1935, for two plats, are shown in Table 3. The loss of water and solids in the run-off from eight plats after 1.4 inches of rainfall on June 18, 1936, which occurred in about 10 minutes, are shown in Table 4. The data on the population in the soil and in the run-off from May through October 1936 are shown in Table 5.

It appears from the agar plate count and from the determination of the number of organisms of the various physiological groups that there were in several instances 180 to 400 times as many organisms in the run-off for each gram of solid material as there were in the soil from which the run-off came.

TABLE 1.—*Number of organisms in the unfertilized and cultivated soil and in the run-off from the soil, Plat A II, 1935.**

Number determined by	Source of sample and date																
	Soil												Run-off				
	June 17	July 3	July 17	July 24	July 30	Aug. 8	Aug. 21	Aug. 31	Sept. 12	Sept. 24	Oct. 10	Nov. 3	July 8	July 13	Aug. 27	Oct. 23	Oct. 29
Agar-plate†	6	3	6	3	2	9	21	6	4	2	6	20	48	10,871	720	169	85
Dilution count:																	
In peptone broth†	1	1	10	1	1	1	10	1	10	1	1	10	91	580	312	4	—
Ammonifiers†	0.1	1	10	0.1	1	1	10	0.1	1	1	1	1	91	560	312	4	—
S-oxidizers‡	0.01	0.01	0.05	0.05	0.01	0.01	0.05	0.1	0.1	0.1	0.05	0.5	0.1	0.05	0.15	0.47	—
Nitrifiers‡	1	1	1	1	1	1	10	5	5	5	10	10	23	56	76	4	—
Anaerobes‡	—	0.1	0.1	0.1	0.01	0.1	1	0.01	25	0.1	0.1	0.1	—	5	0.3	0.5	—
Cellulose‡	0.01	0.1	0.1	0.1	0.1	1	1	0.1	1	1	1	1	0.09	58	27	12	—
Rhizobia trifolii	1	10	1	1	1	0	100	100	10	10	100	10	1	58	3	3	—
Fungi§	14	12	9	14	13	9	10	17	11	9	19	30	145	3,645	1,400	761	110
Algae‡	0.25	0.01	0.05	0.5	0.5	0.5	0.5	1	1	0.5	1	10	0.22	0.29	78	4.7	—
Rainfall, inches	—	—	—	—	—	—	—	—	—	—	—	—	0.91	0.40	1.02	0.47	1.63
Water loss, inches	—	—	—	—	—	—	—	—	—	—	—	—	0.166	0.009	0.067	0.004	0.016
Water loss, tons per acre	—	—	—	—	—	—	—	—	—	—	—	—	18.77	2.03	7.57	0.45	1.80
Soil loss, lbs. per acre	—	—	—	—	—	—	—	—	—	—	—	—	240	4	48	2	4

*Plat size 72.6 feet long, 6 feet wide.
†Multiply by 1,000,000.
‡Multiply by 1,000.
§Multiply by 10,000.

TABLE 2.—*Number of organisms in the virgin, fertilized soil and in the run-off from the soil, 1935.**

Number determined by	Source of sample and date																	
	Soil													Run-off				
	June 6	June 17	July 13	July 17	July 24	July 30	Aug. 8	Aug. 21	Aug. 31	Sept. 12	Sept. 24	Oct. 10	Nov. 3	July 8	Aug. 13	Aug. 27	Sept. 23	Sept. 29
Agar plate†	1	9	3	1	4	1	11	7	14	3	3	3	3	23	11,053	6,925	77	600
Dilution count:																		
In peptone broth†	1	1	1	10	10	10	10	1	1	10	1	1	1	14	454	3,120	45	—
Ammonifiers‡	1	1	10	1	0.1	10	10	10	10	1	10	10	10	10	454	31,200	450	—
S-oxidizers§	0.1	0.1	0.1	0.5	0.1	0.1	1	0.1	1	10	0.5	0.1	0.5	1.4	4.5	3.6	2.3	—
Nitrifiers§	10	10	10	10	50	10	10	100	100	250	250	250	100	142	23	714	450	—
Anaerobes§	0.01	—	1	1	0.1	1	1	1	1	10	1	1	1	—	45	71	400	—
Cellulose§	1	1	0.1	1	1	1	1	1	1	10	10	1	1	1	45	92	1,130	—
Rhizobium trifolii§	0.01	0.01	0.01	0	0.01	0.01	0.01	0.1	0.1	10	10	1	1	0.01	0.05	0.07	0.04	—
Fungi‡	2.3	3.2	4.3	2.2	0.21	1.8	2.7	2.1	3.3	2.3	2.4	1.6	2.2	10	20	2.170	90	16
Algae**	0.025	0.010	0.025	0.100	0.100	0.050	0.05	0.025	0.10	1	0.050	0.10	5	0.025	0.227	17.8	27.0	—
Rainfall, inches	—	—	—	—	—	—	—	—	—	—	—	—	—	3.46	0.40	1.02	0.47	1.63
Water loss, tons per acre	—	—	—	—	—	—	—	—	—	—	—	—	—	17.19	0.113	4.75	1.01	1.13
Soil loss, lbs. per acre	—	—	—	—	—	—	—	—	—	—	—	—	—	194	1	16	5	1

*Plat size 132 feet long, 33 feet wide.
†Multiply by 1,000,000.
‡Multiply by 100,000.
§Multiply by 100.
**Multiply by 10,000.

TABLE 3.—*Rainfall and quantity of run-off with solids in the run-off (acre basis), 1935.*

Date	Rainfall, inches	Run-off			
		Plat A5, corn		Plat E2, corn-oats	
		Water in tons	Solids in pounds	Water in tons	Solids in pounds
July 8	2.89	326.89	6,210	25.56	1,400
Aug. 13	0.40	2.48	51	3.73	78
Aug. 27	1.02	19.68	473	18.41	370
Oct. 23	0.47	2.26	46	2.94	18
Oct. 29	1.63	9.95	86	5.09	9

TABLE 4.—*Loss of water and solids in the run-off following 1.4 inches of rainfall, June 18, 1936.*

Plat*	Crops	Cultivation	Run-offs	
			Water, tons per acre	Solids, lbs. per acre
A 3	Corn	Level	75.10	7,586
A 6	Corn	Level	73.06	7,722
A 8	Fallow	Level	80.30	17,141
A 11	Clover	Level	1.47	13
A 13	Clover	Level	1.80	23
E 1	Strip crop corn, oats, clover	Strip	22.05	1,406
E 2	Up and down corn, oats, clover	With slope	20.47	2,849
E 3	Corn, oats, clover	Strip cropped	12.78	469

*A plats 72.6 feet long and 6 feet wide; E plats 132 feet long and 33 feet wide. Duration of rain 10 minutes.

During this study numerous determinations were made of the population in the soil and in the run-off which are not shown in previous tables. The results are so much like those already presented and so voluminous that their presentation in detail seems scarcely necessary. All the data obtained, however, have been arranged in Table 6. In this table all the plats are represented, whether fallow, in rotation, variously fertilized, virgin, strip-cropped, or cultivated up and down the slope. Within the two seasons 108 determinations were made of the population in the soil and 68 in the run-offs from the soil of the same plats. The method by which the various microorganisms were ascertained are indicated in the table. Those organisms in the soil as ascertained by the agar plate method in 1935 totalled about 6.5 millions in a gram while those in the run-off totalled about 2,046 millions. In 1936, the organisms in the soil as ascertained by the same method totalled about 7.3 millions in a gram, while those in the run-off totalled about 1,625 millions. The population of the various physiological groups as ascertained by the dilution

TABLE 5.—*Summary data of population in the soil and in the run-off from the soil, May through October, 1936.**

Number determined by	Source of samples amd plat numbers															
	Soil								Run-off							
	A5	A6	A8	A11	A13	E1	E2	E3	A5	A6	A8	A11	A13	E1	E2	E3
Agar count†	5	7	3	8	9	10	7	9	906	985	708	2,241	3,662	2,242	1,264	976
Dilution counts:																
In peptone broth†	0.9	0.9	0.9	3	3	4	2	4	713	559	167	883	339	141	896	253
Ammonifiers†	0.9	0.7	0.7	3	3	3	2	4	713	559	466	133	339	141	790	253
S oxidizers‡	0.05	0.15	0.06	0.08	0.05	0.05	0.1	0.06	19	2	8	0.9	0.9	2	11	1
Nitrifiers‡	6	4	3	5	6	7	8	9	10	9	49	15	7	22	40	32
Anaerobes‡	2	4	5	8	6	2	3	2	38	107	36	5	1	4	33	844
Cellulose‡	0.4	0.6	2	0.6	0.5	2	2	0.7	177	3	2	224	90	133	335	43
Rhizobium trifolii‡	0.03	2	0.005	0.05	4	2	2	4	0.09	0.3	0.02	0.8	0.05	0.2	0.07	0.6
Fungi†	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.3	5	71	15	18	32	22	54	9
Algae‡	2	2	0.3	0.6	0.8	4	2	20	875	53	247	456	110	319	2,471	484
Water run-off, inches									0.99	1.242	2.68	0.05	0.075	0.302	0.336	0.211
Water run-off, tons per acre									11.2	130.9	353.13	5.65	6.44	34.15	18.0	23.86
Solids lost, lbs. per acre									8,546	7,973	30,179	18	35	1,623	3,653	67

*Average of seven samples from both sources.
†Multiply by 1,000,000.
‡Multiply by 1,000.

method was of the same order, with one exception, though perhaps less pronounced. There appeared to be no more *Rhizobium trifolii* in the run-off than was found in the soil.

TABLE 6.—*Total number of organisms in the soil and in the run-off from the soil for all plats, two seasons, 56 determinations.*

Number determined by	1935		1936	
	Soil	Run-off	Soil	Run-off
Agar plate	6,503,890	2,046,381,120	7,394,458	1,625,861,730
Dilution method:				
In peptone broth	7,004,807	611,285,000	2,633,920	493,630,000
Ammonifiers	2,085,480	574,230,370	2,285,700	424,107,700
Ammonia oxidizers	7,935	38,284	6,222	23,000
Sulfur oxidizers	74	325	79	4,543
Anaerobes	762	6,574	3,961	133,700
Cellulose bacteria	875	17,102	1,030	125,160
Rhizobium trifolii	106	11	1,587	191
Fungi	189,297	9,196,970	201,370	28,266,650
Algae	2,591	55,512	3,967	587,158

Attempts were made to compare the number of organisms in the run-off from the virgin soil with those in the run-off from the cultivated soil. Also, information of a similar nature was sought from plats to which different mineral fertilizers were applied. The data for making the comparisons were so much alike that it was difficult to conclude that the quality or the quantity of the population in the run-off was in any way strikingly dissimilar due to fertilization. The run-off from certain unfertilized plats, however, appeared to carry more fungi, algae, anaerobes, and cellulose-destroying bacteria for each gram of solids in the run-off than did the run-off from fertilized plats, the crops in both cases being the same.

DISCUSSION

In this work no attempt was made to obtain a mechanical analysis of the solids in the run-off. It was suspected that light rains would produce a run-off carrying a high proportion of the finer material, while heavy rains would produce a run-off carrying a sediment more nearly like that of the whole soil. The work of Middleton, *et al.* (9) shows this to be the case. A mechanical analysis, therefore, of the solids in the run-off might explain why the run-off contained a higher population for each gram of solids than was found in the soil from which the run-off came. This should mean that soil with 100% cover would lose a large portion of the fine particles and thus a larger population of the flora than would be the case if a soil were not so well covered. This may explain why the data in certain cases indicated a larger population in a gram of material in the run-off from plats growing crops than was obtained in the run-off from the uncropped plats.

The suggestion by Middleton, *et al.*, was substantiated by these population studies. Total numbers as determined by the agar plate

method showed in the soil before a rainfall of 3.46 inches 1 million organisms in a gram, while in the run-off there were 23 million. In another case, when the rainfall was only 0.4 inch, the population in the soil was about 9 million and in the run-off about 11,053 million. In still another case, before a rainfall of 1.02 inches the population was about 7 million while that in the run-off was about 6,925 million. Such wide differences, however, were not always so regular with total number of fungi.

CONCLUSIONS

The quality and the quantity of the microflora in the soil of the plats and in the run-off from these soils were determined. The counts of the organisms of the various physiological groups were expressed as numbers in each gram of solids. By averaging the data, all determinations show that the total number in the run-off exceeded that in the original soil about 200 times.

The number of ammonia and sulfur oxidizers, of *Rhizobium trifolii*, and of anaerobes that were found in the soil or in the run-off from the soil constituted a small fraction of the total population.

Under the conditions of these tests fertilizers did not affect the number of organisms in the sample of the original soil or in the run-off obtained from the soil.

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SOIL ORGANIC MATTER AND NITROGEN AS INFLUENCED BY GREEN MANURE CROP MANAGEMENT ON NORFOLK COARSE SAND[1]

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THE organic matter of soils is commonly considered to have two functions that bear on soil fertility. One is essentially physical and consists in maintaining soil tilth, holding moisture, and retaining plant nutrients either in an exchangeable form as reported by McGeorge (8, 9)[3] and others, or combined in a less available form as part of the humus body. The other function occurs during the decomposition process and results in the liberation of the combined nitrogen and other nutrients. The retentive function may be comparatively lasting, but the second is temporary and for a given unit of soil organic matter can occur but once. As the rate of decomposition is largely determined by such conditions as temperature, moisture, and aeration which regulate biological activity and since these conditions are favorable in the southeastern states, it follows that the main problems associated with green manuring in this region are to maintain adequate reserves of organic matter by renewal and to regulate the decomposition so that it is of maximum benefit to succeeding crops.

Regional comparisons by Hester and Shelton (3) have correlated the loss of organic matter with annual mean temperatures, while Jenny (5) has concluded that it is difficult to build up organic matter and nitrogen reserves in these warmer regions. The extent of organic matter losses under Sandhill conditions is indicated by lysimeter studies in which more than 50 pounds of nitrogen per acre, equivalent to about 300 pounds of sodium nitrate, leached through a 43-inch profile of fallow Norfolk coarse sand in one winter season after turning under a 7-ton crop of *Crotalaria striata.* Other studies (12) have shown that 77% of the carbon in soybean tops and 90% of the carbon in corn stover was lost from the soil by decomposition within 14 months after application at the rate of 200 tons of fresh material per acre.

FIELD PLOT EXPERIMENTS

This paper summarizes the results of field experiments which were planned to measure the effect of different crop managements on the carbon and nitrogen content of Norfolk coarse sand. The purpose of the work was to obtain information on (a) changes in carbon and nitrogen content of the soil during three cycles of a rotation of le-

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[3]Numbers in parenthesis refer to "Literature Cited", p. 852.

gumes, corn (*Zea mays*), and cotton (*Gossypium hirsutum*) under different fertilizer treatments and different winter management; (b) the quantity of organic matter added to the soil by the whole plant and by the stubble and roots of certain legumes; and (c) the stimulation of succeeding crop growth by the various green manuring treatments.

The rotation experiment consisted of growing legumes, corn, and cotton in replicated field plots on Norfolk coarse sand at the Sandhill Experiment Station, Columbia, S. C., from 1929 to 1937. The details of the experimental outline and some of the results of the first two rotations have already been described (1, 2, 10, 11). The legumes used in the different plots were soybeans (*Soja max*), velvet beans (*Stizolobium deeringianum*), and cowpeas (*Vigna sinensis*). These were turned under as green manure and followed by corn the first year and cotton the second year, which were fertilized with 400 and 800 pounds per acre, respectively, of a 2–8–4 ($N-P_2O_5-K_2O$) fertilizer. On an adjacent series of plots the same kinds of legumes were removed as hay and the stubble was turned. The corn and cotton on these plots were fertilized with a 6–8–4 mixture at the rate of 400 and 800 pounds per acre, respectively. The legumes turned under as green manure were fertilized with 400 pounds per acre of a 2–8–4 mixture and those removed for hay received 400 pounds of a 6–8–4 fertilizer.

The experiment also included a series of plots on which a winter cover crop of rye (*Secale cereale*) was planted in the fall following cowpeas, thus providing a cover crop on the area one winter in three.[4] The rye was not fertilized. Samples of soil were collected from the surface horizon of each plot in the spring and fall and were analyzed for carbon and nitrogen.

RESULTS OF THE FIELD EXPERIMENTS

The annual changes in soil carbon and nitrogen of the plots where cowpeas, soybeans, and velvet beans were grown and turned under as green manure in rotation with cotton and corn are shown in Fig. 1. There was a decrease in carbon content of the soil during the course of the experiment. This decrease was greatest during the first 2 years.

The change in average nitrogen content of the soil was small, but there were comparatively large semi-annual changes in nitrogen during the last 3 years, the values in all treatments being lower in the spring than in the fall. It seems likely there was a fixation of nitrogen in the soil during the summer and a liberation, possibly by conversion to nitrate and subsequent leaching, during the winter, but it is not known why this effect should have become so marked during the last 3 years and was not apparent during the early part of the experiment. During this last 3-year period, crop yields were low. Since the carbon decreased and the average nitrogen content did not change appreciably, there was a decrease in the carbon-nitrogen ratio of the soil under all three legumes from about 26:1 to about 17:1. No beneficial effects on soil fertility, as indicated by crop yields, accompanied this decrease in carbon-nitrogen ratio.

[4]Vetch and rye planted but negligible amounts of vetch were obtained.

If any of the three legumes had had more effect on the soil organic matter than the others, it should have been cumulative during the 9-year period and a divergence of the data represented in Fig. 1 would have appeared. However, the curves representing the soil composition from each of the legume treatments do not show any consistent trends, which indicates that there was no outstanding difference in the effects of cowpeas, soybeans, and velvet beans used as green manure on this soil, although the values for soil nitrogen are slightly lower and resultant carbon-nitrogen ratios slightly greater in the cowpea plots during the second to seventh year of the experiment.

The data of Fig. 1 were obtained from average values of the plots during the rotation and thus each point on the curve is an average value of soil which had been cropped to the indicated legume, corn, and cotton. This procedure would have shown any cumulative effect but might have masked any short time influence of these crops when considered separately.

Fig. 2 was obtained by averaging the data with respect to the crop grown, thus yielding a curve each point on which represents an average value for 9 years under the indicated crop. No marked changes in

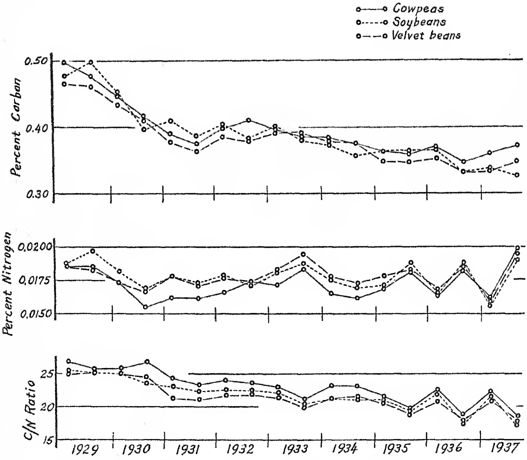

FIG. 1.—Comparative effect of cowpeas, soybeans, and velvet beans used as green manures in a 3-year legume-corn-cotton rotation on the carbon and nitrogen content and the carbon-nitrogen ratio of Norfolk coarse sand. The points, charted each year, give the average soil analyses in spring and fall, respectively.

soil composition can, with certainty, be ascribed to the growth of the different crops except that the somewhat lower nitrogen values and higher carbon-nitrogen ratios for cowpea plots are apparent.

The experiment provided for the comparison of two crop management systems, *viz.*, turning the entire legume as a green manure with use of a low-nitrogen fertilizer on the following corn and cotton, and removal of the legume as hay with use of a high-nitrogen fertilizer on the following corn and cotton. The changes in soil carbon and nitrogen from these treatments were similar for each of the legumes. The data for all three legume treatments were therefore averaged and these average results for the two systems are given in Fig. 3. The curves indicate that turning under the whole plant and use of a 2–8–4 fertilizer did not increase either the permanent soil carbon or nitrogen compared with the quantity present when only the stubbles were turned and the crops were fertilized with a 6–8–4 mixture. In fact, the trends in Fig. 3 indicate that turning under the entire plant resulted in a slightly lower carbon and nitrogen content of the soil than turning under the legume stubble. The carbon-nitrogen ratio of the soil resulting from the two systems was similar.

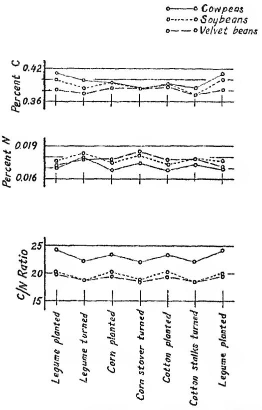

FIG. 2.—Comparative effect of cowpeas, soybeans, and velvet beans, each in rotation with corn and cotton, on the carbon and nitrogen content and the carbon-nitrogen ratio of Norfolk coarse sand. Average of 9 years. "Crops planted" indicate soil analyses in the spring at planting time, and "crops turned" indicate analyses at time crops were turned under in the fall.

A comparison of cowpeas followed by a winter cover crop of rye versus cowpeas followed by winter fallow was provided in one series of plots. It is apparent from Fig. 4 that a winter cover crop of rye once in 3 years maintained the carbon and nitrogen at a higher level than comparably managed plots that were continuously winter fallowed. The carbon-nitrogen ratio of the soil in the winter rye plots was similar to that in the soil of the winter fallow plots, indicating a possible similarity in the chemical composition of the soil organic matter in both cases and merely a change in the quantity present, rather than a difference in its chemical composition.

Crop yields were determined during the experiment. These varied from year to year. The yield of green vegetation was converted to relative yields, taking the yield on the cowpea-winter fallow plot of each fertilizer management each year as unity. There was a con-

siderable degree of association between the yield of crops and the soil carbon and nitrogen data. Soybean and velvet bean yields during the 9-year period averaged 94% and 157%, respectively, of the cowpea yields on those areas where the crop was removed as hay and the stubble only was turned. Corresponding figures for soybeans and velvet beans on the plots where the entire crop was turned under were 90% and 145% of the cowpea yields, respectively. From con-

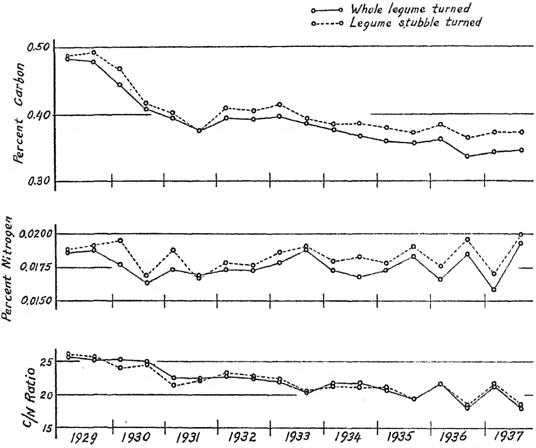

FIG. 3.—Comparative effect on the carbon and nitrogen content and the carbon-nitrogen ratio of Norfolk coarse sand of turning under whole legumes versus removal of the legumes as hay and turning the stubble, during a 3-year rotation of legumes, corn, and cotton. Points charted each year represent average soil analyses of samples taken in the spring and fall, respectively.

sideration of the individual data, it is believed that the difference between the soybean and the velvet bean yields were significant but that the differences between the cowpea and soybean yields were not significant.

The average yields of corn and cotton following soybeans and velvet beans were 114% and 98%, respectively, of those following cowpeas where the hay was removed and stubble only turned under, and 116% and 100%, respectively, where the whole plant was turned as green manure. Thus, soybeans used as a green manure produced slightly larger yields of following corn and cotton than cowpeas or velvet beans, which appeared to be about equally effective as green manure crops under the conditions of this experiment. Therefore, the greater

tonnage of velvet bean green manure turned under was no more beneficial than cowpeas and less effective than soybeans in stimulating the growth of the corn and cotton which followed. Where rye was used as a winter cover following cowpeas, the average yield of corn and cotton was increased over the winter-fallow treatments by 35% on the plots where the cowpea hay was removed and stubble turned and 46% on the plots where the cowpeas were turned as

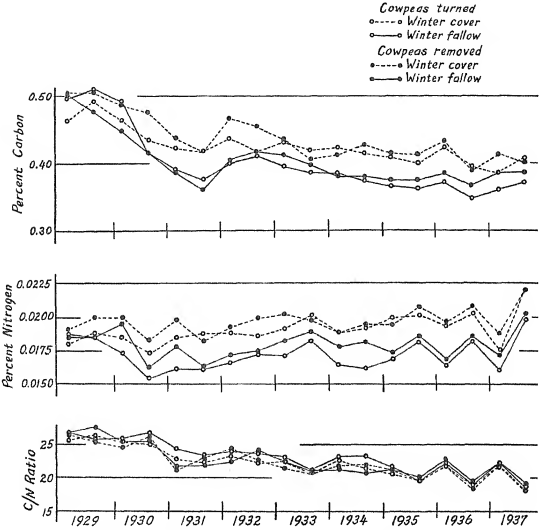

FIG. 4.—Effect on the carbon and nitrogen content and the carbon-nitrogen ratio of winter rye and winter fallow following turning of cowpeas as green manure and cowpea stubble during a 3-year rotation of cowpeas, corn, and cotton. Points charted indicate average soil analyses of samples taken each year in the spring and fall, respectively.

green manure. These differences between winter fallow and winter rye management were in the same direction in 35 of the 36 possible comparisons.

LYSIMETER EXPERIMENTS

In addition to the field experiment discussed above, green manuring experiments were conducted in lysimeters during a 5-year period for the purpose of observing the relationships between leaching, soil

composition, and crop growth. The lysimeters contained a 43-inch profile of virgin Norfolk coarse sand and were 0.0005 acre in area. *Crotalaria striata* and cowpeas were grown as green manure crops in 1933 and 1934 to establish soil fertility differences and an indicator crop of pearl millet (*Pennisetum glaucum*) was grown from 1935 to 1937 to measure these differences agronomically. Winter rye followed the legume in one pair of tanks, while the other pair were winter fallowed. The pearl millet was cut for hay and all the tanks were winter fallowed during the indicator crop period. The legumes and pearl millet were fertilized with a 4–8–4 mixture at the rate of 400 pounds per acre. One lysimeter was maintained continuously fallow and similarly fertilized as a control.

Fig. 5 compares the effect on the soil carbon and nitrogen of the two green manure crops. In general, there was no important or highly significant change in carbon during the 2 years that legumes were grown but considerable change occurred during the succeeding 3 years of the indicator crop period. There was a loss of carbon in the uncropped control tank except in the spring of 1936. There was no significant change in carbon where the crotalaria or cowpeas were turned under in absence of a winter cover, but a definite increase where crotalaria was turned and followed by winter rye. There was a slight loss of nitrogen from the control tank. The nitrogen of the cropped tanks increased, particularly in the crotalaria tanks. The increase was greater where winter cover was used than under winter fallow management. This increase was small while the tanks were cropped to legumes, but, particularly in the case of the crotalaria, increased markedly after the tanks were cropped to pearl millet.

The combined carbon and nitrogen effects are reflected in the carbon-nitrogen ratio, which decreased slightly in the cowpea tank and decreased appreciably in the crotalaria tanks, the lower C/N ratios in general being associated with the winter cover management. This change occurred during the period when legumes were grown, and remained constant later when the tanks were cropped to pearl millet, indicating a change in the composition of organic matter resulting from growing these crops. The carbon-nitrogen ratio of the fallow tank increased from spring to fall in 1936, 1937, and 1938 in a manner similar to the field experiment, the average value remaining constant throughout the experiment. This seasonal fluctuation was not noted in the cropped tanks.

The yield of crotalaria and cowpeas was somewhat similar in 1933 and in each case was the same on the tanks which were to receive a winter cover and a fallow management. Crotalaria yields were more than double cowpea yields in 1934, and were increased slightly by the rye crop planted in the fall of 1933 and turned in the spring of 1934. An excellent crop of pearl millet was obtained in 1935. The yield of pearl millet following crotalaria was considerably greater than that following cowpeas and was materially improved by turning winter rye. The pearl millet crops in 1936 and 1937 were much smaller but still showed the benefit of the winter cover crops planted in 1933 and 1934 and gave larger yields following crotalaria than following cowpeas.

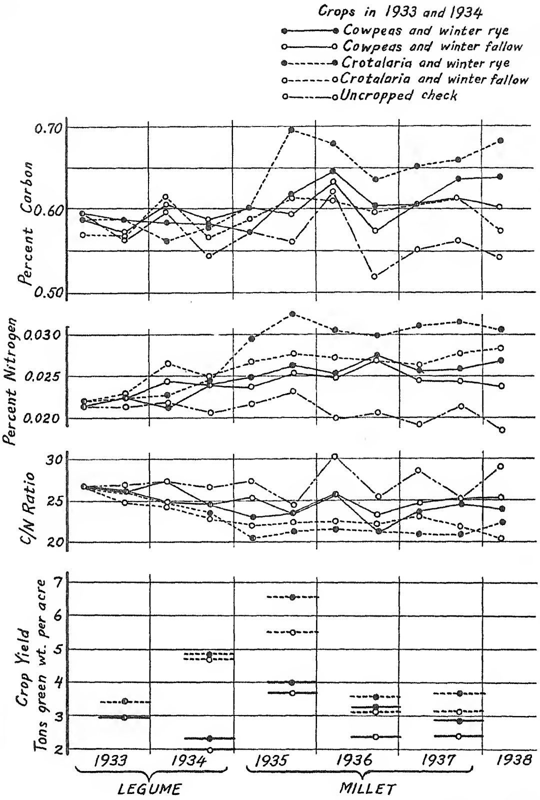

FIG. 5.—Effect of growing and turning under cowpeas and *Crotalaria striata* as green manures, with and without winter rye, on the soil carbon and nitrogen content and the carbon-nitrogen ratio of Norfolk coarse sand in lysimeters and on the yield of following crops of pearl millet.

DISCUSSION

There has been a large amount of research devoted to green manuring and the decomposition of organic residues in the soil. The agronomic phases up to 1926 have been ably reviewed by Pieters (15). In general, it seems clearly established that green manures improve the yield of following crops on nearly all soils where moisture is not a limiting factor, the percentage increases being larger as the inherent fertility of the soil is less. Legumes are generally considered superior to non-legumes for soil improvement purposes.

Lyon (6, 7) and others have shown that the effectiveness of green manures is not entirely a matter of quantity, but there are specific, although unknown, qualitative effects which make some plant species superior to others under different conditions and for various following crops. It seems to be generally accepted that green manures of any kind increase the content of soil organic matter, although the extent of such increase may be materially influenced by various conditions, such as liming (13, 14).

Since increased crop yields and gains in soil organic matter both result from green manuring, it would appear that the increased yield of the following crop is a result of the increase in soil organic matter and that there might be some direct relationship between the two. However, there is little published data which directly applies to such a theory. These experiments on Norfolk coarse sand show that under winter fallow conditions the following crop yields were not proportional to the amount of green manure turned and that measurable increases in soil organic matter were not followed by greater crop yields. It was also found in the field experiment that removal of the above-ground portion of legumes receiving a 6–8–4 fertilizer and turning only the root and stubble portions resulted in more, rather than less, soil carbon and nitrogen than was obtained by turning the entire legume fertilized with a 2–8–4 mixture. The difference in fertilizer used in the field experiments probably does not explain the observed differences since similar results were obtained in the lysimeter under uniform fertilizer management.

Rye as a winter cover following summer legumes in a rotation of corn and cotton slowed down the loss of carbon and prevented the depletion of soil nitrogen as compared with the same rotation where winter rye was omitted. Except for the cultivation of winter rye, the chief difference among the various treatments was the use of roots and stubbles as a source of soil organic matter in some of the treatments in contrast to the use of the entire plant in the others. The data show that where roots and stubble were turned, both soil carbon and soil nitrogen were maintained at a higher level than where the legume tops were also incorporated in the soil. Legumes tops are rich in nitrogen, calcium, and other nutrients compared with legume roots and stubble. The tops decomposed rapidly after turning, releasing their contained nutrients and stimulating microbiological activity to such an extent that nearly all the added material and also more or less of the original soil organic matter was decomposed. In contrast, the more woody and less readily decomposable root and stubble portions did not stimulate microbiological activity to the same extent

as the tops, consequently the decomposition that occurred extended over a much longer period during which there was apparently time for the observed fixation of nitrogen.

The data indicate that under the conditions of these experiments, non-legumes and particularly roots and stubbles were more effective than whole legumes in maintaining both the carbon and nitrogen content of the soil and consequently were more efficient in building up the supply of organic matter, but there is no evidence that the increase of organic matter thus established is in itself beneficial to the growth of the following crops. In the lysimeter experiment, the large increases of soil carbon and nitrogen in 1935 were followed by reduced yields of millet in 1936. The data show that increased yields of following crops occurred where the greatest amount of added organic matter decomposed. From this, it appears that the decomposition of organic matter with the release of its contained nutrients is the function that stimulates crop growth and that the chief benefits of green manuring are obtained when conditions are established for its destruction by decomposition processes.

These experiments did not provide data for the comparison of rye with legumes as a source of soil organic matter, although the combination of rye and legumes resulted in higher fertility and more organic matter in the soil than use of legumes alone. Unpublished lysimeter experiments have shown that in addition to the benefits resulting from the organic matter turned into the soil when the winter cover crop is plowed under, rye also conserves the nutrients released during the decomposition of the green manures turned under in the fall. This is important under Sandhill conditions as the decomposition of succulent material turned under in the fall is largely completed during the winter before spring crops are planted and under fallow conditions the nutrients would be released and leached from the soil before they could be utilized by the following summer crop. A winter cover crop of rye absorbs these nutrients and holds them during the winter, as shown by Hill (4). When it is plowed under in the spring and allowed to decompose, these nutrients are released at the time they are of benefit to the summer crop.

SUMMARY

Changes in the carbon and nitrogen content of Norfolk coarse sand resulting from the growth of different green manure crops were determined semi-annually. Soybeans and velvet beans used as green manures in field plots in a 3-year rotation of legumes, corn and cotton were generally similar in their effects. The soil of the cowpea plots was a little lower in nitrogen and had a higher carbon-nitrogen ratio. Soil carbon and nitrogen were lower when the entire legume, fertilized with a 2% nitrogen mixture, was plowed under than when the legume stubble grown with a 6% nitrogen mixture was turned. A summer green manure crop followed by a winter cover crop of rye maintained the soil carbon and nitrogen at a higher level than a summer cover crop with winter fallow management. Cotton and corn yields were improved following the use of leguminous green manures in summer followed by winter rye.

Crotalaria striata and cowpeas, with and without a winter cover crop of rye, were grown 2 years in lysimeters. These were followed by pearl millet without a winter cover crop for 3 years. A marked increase in soil carbon and nitrogen occurred in the crotalaria tanks after they were planted to pearl millet. Pearl millet yields were greater following crotalaria than following cowpeas and were increased by a winter cover crop of rye compared with winter fallow.

The results indicate that maximum benefits of green manuring are obtained by storing organic matter with its contained nutrients during the soil improvement period and then releasing the nutrients by decomposition of the organic matter at the time they are of most benefit to the following crop. On porous soils, winter cover crops are needed to hold the nutrients released by the decomposition of a summer green manure until the next season's crop can utilize them.

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SOME FACTORS WHICH INFLUENCE INFILTRATION AND ITS MEASUREMENT IN HOUSTON BLACK CLAY[1]

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INFILTRATION has received added consideration recently due to the importance of this process as it is related to soil and water conservation practices. While its importance has been recognized, infiltration data applicable to different land and cover conditions remain limited. In an effort to furnish these data a number of investigators have sought to develop a method whereby an index of the infiltration associated with field areas under conditions of natural rainfall can be obtained. Some knowledge of the conditions influencing soil permeability will be recognized to be of equal importance. The limitations of results obtained by various methods for estimating the infiltration which will occur in field areas can be judged only if the process involved is understood. It seems probable also that a better knowledge of the factors which influence soil permeability would contribute much to the development of conservation practices which would incorporate the most effective functioning of this important process.

The results of some exploratory infiltration tests made on Houston black clay, following the general procedure outlined by Musgrave (4),[3] indicated that individual measurements obtained by this method varied widely. A series of infiltration tests were made to check preliminary tests and to determine if a usable index of infiltration could be obtained. Supplementary studies were made of conditions in the soil cylinders which might be expected to modify soil permeability.

METHODS AND PROCEDURE

Two areas of Houston black clay were selected. These areas were similar in all respects except their present cover and cultural history. The soil in both areas developed from parent material representing the same geologic section. One area retained its virgin vegetative cover of native prairie grasses and the other was a cultivated area cropped to cotton. The cultivated area had been under cultivation for over 50 years, being utilized over this period chiefly for the production of cotton and corn.

Infiltration rates[4] on soil cylinders were determined in a manner similar to the procedure outlined by Musgrave (4). Briefly, it consisted of jacking steel tubes into the ground and adding water to the surface of the soil inclosed by the tube at a rate equal to the rate of penetration. The addition of water was made from a burette, the additions being controlled automatically by the water level in the tube. The quantity of water penetrating the soil was determined from burette readings made periodically. To minimize the influence of soil variation

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[3]Figures in parenthesis refer to "Literature Cited", p. 866.

[4]Glossary of terms used in Soil Conservation Service. SCS-MP-15, October. 1936.

the tubes were installed as close together as seemed practical. The tubes used were 6 inches in diameter and of two length groups, 19 inches and 38 inches, respectively. In the meadow area a group of five 19 inch and five 38 inch tubes were installed in two rows of five tubes each. The rows were 2 feet apart and the tubes 2 feet apart in the rows. The tubes representing the two length groups were installed at random. A group of five 19 inch tubes were installed in the cultivated area in one row with the same spacing. Prior to the application of water a perforated disc was placed on the surface of the soil, the sparse second growth of dry grass which occupied the meadow area being first cut close to the ground in the tubes.

Just prior to beginning the infiltration tests the soil was sampled at six points surrounding the group of tubes in the meadow area and five points surrounding the tubes in the cultivated area. At each sampling point samples were obtained for the following depths: 0–6 inches, 6–12 inches, 12–24 inches, 24–36 inches, 36–48 inches, and 48–60 inches, and the moisture content determined. The moisture content of the soil in the tubes at the begining of the test was computed from the average moisture content of these samples.

The elevation of the soil surface inside and outside each tube was determined from a fixed point on the tube before the addition of water and after the completion of the measurement for the purpose of determining the volume occupied by the incased cylinder of soil at the two moisture contents.

The infiltration tests were made in the two areas in close succession. Water was supplied to all the cylinders at one site simultaneously, the initial additions to the individual cylinders being spaced in a manner which would distribute the time for making the required observations. Burette readings were taken every 5 minutes for the first 20 minutes, then every 10 minutes until the end of the first hour. During the second hour readings were taken every 15 minutes, and during the remainder of the test readings were taken every half hour. The application of water was continued for 48 hours.

Immediately upon completion of the measurements two tubes of each length, one in which the infiltration had been very high and one in which it had been very low, were excavated. The tubes and incased soil cylinders were weighed, following which the soil was carefully removed from the tubes, dried at 110° C, reweighed, and the weight of dry soil and moisture content computed. A careful visual check was made during the time the soil was being removed from the tube for water passageways and structural differences which might be used to interpret the different infiltration values obtained.

The remaining six tubes in the meadow area and the remaining three in the cultivated area were left in place for 41 days, following which infiltration was measured again to determine what, if any, effect long-continued high moisture content had on soil permeability. These cylinders of soil were maintained at approximately field capacity during this interval by the addition of water periodically and protection against evaporation losses by the use of moist felt discs on the soil surface supplemented by loose-fitting covers over the tubes. Following the second measurement the tubes in the meadow were left in place with the soil surface protected from drying by the moist felt disc and the tube covers for 13 days, to provide an opportunity for complete drainage of gravitational water. At the end of this period the tubes were excavated and the weight of dry soil and moisture content determined as in the case of the cylinders removed after the first measurement. The second infiltration measurement on the cylinders of cultivated land covered 34 days, immediately following which the

tubes were excavated and the dry soil and moisture content determined as previously outlined. Time was not allowed for the soil to drain since the movement of water through the incased soil cylinder was so slow the possibility of establishing an equilibrium in a reasonable length of time seemed doubtful.

To afford a means of studying the percolation[5] process and its relation to pore space and moisture distribution, two long and two short tubes were installed in the meadow area and two short tubes in the cultivated area. Following the installation the tubes were excavated. These incased soil cylinders were transported to the laboratory and infiltration determined there in a manner similar to that by which it was determined in the field. To obtain an accurate measure of the moisture content each tube and incased soil cylinder was weighed before and after the measurement. As a means of studying the relation between the entrance of water into the soil and its subsequent distribution in the soil, the time required for percolation to begin was noted, as also the quantity of water which had entered the soil at the time percolation began.

The percolate was measured periodically during the time water was added to the soil and for the period between the time the water just disappeared from the surface of the soil until drainage stopped in an effort to learn something of the time required to saturate the soil and the quantity of gravitational water present at saturation. Following the completion of the measurement, the soil was removed from the tubes, dried, and weighed.

RESULTS AND DISCUSSION

The highly variable infiltration rates indicated by preliminary tests on in-place cylinders of field soil were confirmed. A number of investigators have called attention to the wide variation in the permeability exhibited by soil cylinders representing a given soil and field condition and emphasized that field infiltration characteristics must be based on a value obtained through the use of a large number of cylinders.

Slater and Byers (6) conclude that water passageways provided by root channels and structural cleavage govern field percolation rates more than the character or volume of the pore space of the soil mass. The infiltration rates obtained on incased cylinders of Houston black clay under both field and laboratory conditions support these conclusions. Examination of the soil cylinders after the 48-hour tests showed that even where large quantities of water had passed through the cylinders, the soil had not always been uniformly wetted but contained vertical zones exhibiting different degrees of wetness. The soil material in the wetter zones appeared to have a slightly looser structure. The infiltration in 48 hours could be accounted for in seven of the cylinders by the increase in moisture content of the cylinder. An examination of these cylinders gave no evidence that water had percolated through them. The soil in the upper portion of these cylinders was wet, but the soil underneath had received little or no water.

While, as previously stated, the infiltration rate as determined for individual soil cylinders varies within wide limits, there appears to be a significant difference in the rate and the change in rate with

[5]See footnote 4.

time directly attributable to soil and experimental conditions. The highest rates were obtained on the short cylinders from meadow land and the lowest on the cylinders from cultivated land. The initial infiltration rate obtained in every test was high. There was less difference between rates obtained on the three groups of cylinders representing different land and experimental conditions, initially, than was obtained as the application of water continued. As the time of application increased, rates obtained on each group became more widely different. It will be observed (Table 1 and Fig. 1) that the infiltration rates approached minimum values after 2 hours in the cultivated area but that 12 to 24 hours or longer were required for the rates on the two groups of cylinders in the meadow area to approach

TABLE 1.—*Infiltration rates determined on cylinders of undisturbed soil.*

Soil cylinder	Initial length, inches	Infiltration rate, surface inches per hour							Per-colate, surface inches, 0–48 hrs.*
		0–5 min.	5–30 min.	½–2 hrs.	2–12 hrs.	12–24 hrs.	24–46 hrs.	46–48 hrs.	
				Cultivated Land					
1†	17.1	11.16	0.60	0.17	0.05	0.02	<0.01	<0.01	0.0
2	16.6	21.00	1.94	0.26	0.05	0.01	0.02	0.01	0.0
3	16.8	24.84	1.10	0.31	0.06	0.02	0.02	0.02	0.0
4	16.9	13.44	1.99	0.50	0.12	0.02	0.01	0.01	0.2
5	16.4	17.52	2.18	0.37	0.11	0.03	0.01	<0.01	0.0
6	16.4	62.04	2.76	0.61	0.15	0.06	0.06	0.06	5.8
Average	16.7	25.00	1.76	0.37	0.09	0.03	0.02	0.02	
				Meadow Land					
11	15.5	34.68	5.06	1.03	0.25	0.15	0.12	0.12	10.6
12	16.1	46.08	16.27	4.45	1.97	0.58	0.28	0.18	46.1
13†	17.1	29.52	15.46	6.59	1.63	0.59	0.40	0.39	46.4
14†	17.1	30.00	23.04	10.03	4.31	2.97	1.41	0.98	133.8
15	16.1	37.32	18.74	12.66	6.48	3.30	1.62	0.84	168.9
16	16.4	33.60	35.30	24.59	12.27	5.14	4.26	3.24	335.0
17	15.6	42.36	48.77	37.01	19.72	8.73	6.23	4.82	524.3
Average	16.3	36.22	23.23	13.77	6.66	3.07	2.05	1.51	
				Meadow Land					
21†	34.0	30.36	3.07	0.03	<0.01	<0.01	<0.01	< 0.01	0.0
22	33.5	23.64	5.26	0.27	0.04	0.01	0.01	0.01	0.0
23	34.9	30.00	5.04	0.02	<0.01	<0.01	<0.01	<0.01	0.0
24†	35.5	49.56	15.14	4.05	0.34	0.11	0.07	0.05	14.6
25	34.9	36.60	24.31	5.58	0.37	0.08	0.05	0.04	19.6
26	34.5	37.32	15.38	12.05	5.48	1.56	0.69	0.48	109.9
27	34.8	65.88	25.46	11.21	5.56	2.59	0.64	0.46	127.2
Average	34.6	39.05	13.38	4.74	1.69	0.62	0.21	0.15	

*Computed for cylinders run in field. Measured on cylinders run in laboratory.
†Cylinders excavated prior to making infiltration determinations.

a minimum value. The time required on the average for infiltration to approach a constant rate was greater for the short cylinders than for the longer cylinders.

These results are better understood when the physical and chemical characteristics and initial field condition of the soil are noted. Mechanical analyses (5) and moisture equivalent (2) determinations of samples obtained adjacent to the location at which the infiltration tests were made indicate the uniformity of texture and heavy nature of the soil (Table 2). An intensive study of the physical and chemical

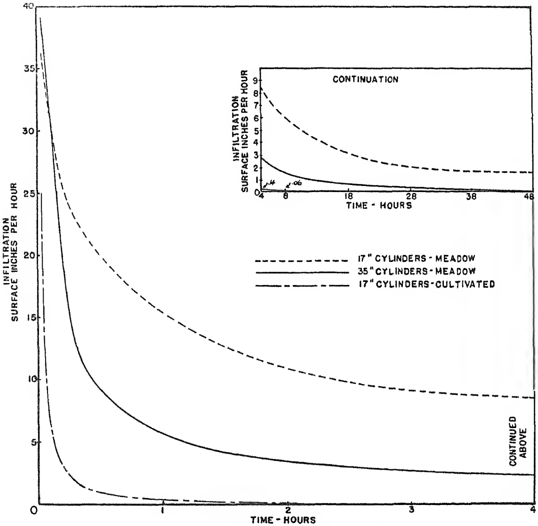

FIG. 1.—Infiltration rates, average of cylinder groups.

properties of Houston black clay is reported by Middleton, *et al* (3). Field observations at the time the tests were made indicated dry weather cracking was general and that cracking was more intensified in the meadow than the cultivated land. The surface of the meadow land had a granular structure with many fine interconnecting cracks. Below the surface 6 inches cracks were numerous but became less frequent with increasing depth. The cracks attained their maximum size at a depth of about 2 feet. In the cultivated area the cracks were obscured by the loose surface soil, but below this they were well defined but less numerous and not as deep as in the meadow area,

The difference in the extent of cracking in the two areas is indicated by the different moisture content of the soil in the two areas (Table 3).

TABLE 2.—*Mechanical analyses and moisture equivalents of samples taken near infiltration tubes.*

Depth, inches	Sand, 2.0–0.05 mm, %	Silt, 0.05–0.002 mm, %	Clay, <0.002 mm, %	Organic matter by H_2O_2, %	Moisture equivalent, %
		Meadow Land			
0–2	9.8	35.8	49.4	5.0	41.2
5–7	7.8	35.8	52.6	3.8	40.7
11–13	8.2	37.2	53.2	1.4	37.2
23–25	7.9	38.2	53.1	0.8	34.1
35–37	7.4	38.2	53.2	1.2	34.3
47–49	5.8	42.0	51.5	0.7	34.6
59–61	5.2	41.8	52.4	0.6	36.3
		Cultivated Land			
0–2	13.6	34.0	51.0	1.4	33.5
5–7	9.0	35.3	54.5	1.2	38.1
11–13	9.0	35.2	54.9	0.9	39.0
23–25	7.8	36.0	55.2	1.0	42.1
35–37	7.7	37.8	53.9	0.6	49.0
47–49	8.0	37.2	54.1	0.7	51.2
59–61	7.7	37.2	54.4	0.7	50.0

TABLE 3.—*Soil moisture.*

Depth interval, inches	Percentage moisture						Average, %
				Meadow Area			
0–6	14.9	14.1	16.5	14.5	14.3	16.7	15.2
6–12	18.1	18.9	18.2	17.0	17.5	19.8	18.2
12–24	16.6	18.1	16.9	16.3	17.2	18.1	17.2
24–36	16.8	17.7	17.2	16.1	17.3	17.9	17.2
36–48	18.9	19.1	17.8	17.8	18.3	18.6	18.4
48–60	19.7	20.5	19.5	21.1	20.3	19.9	20.2
				Cultivated Area			
0–6	13.7	12.6	13.2	11.4	13.4	—	12.9
6–12	20.8	20.3	19.9	15.1	22.2	—	19.7
12–24	22.5	23.0	22.2	19.6	23.5	—	22.2
24–36	23.7	24.0	23.9	22.4	23.4	—	23.5
36–48	24.7	25.3	23.7	23.6	24.0	—	24.3
48–60	26.1	26.8	25.7	24.4	17.6	—	24.1

The observed vertical zones of different wetness indicate the presence of water passageways. The assumption that continuing high rates contributing to deep percolation are dependent upon the presence of water passageways rather than total porosity is supported by the fact that in the cylinders through which little or no water percolated the infiltration rates dropped very abruptly to near the

minimum rate. Also, that if percolation through the cylinder took place at all, it occurred in the first few minutes after the initial application of water, as will be indicated by data to be discussed later in the paper (Table 7). A volume of water, equal in some cases to 30 times the volume of the cylinder, percolated through the cylinder in 48 hours. This is evidence that water is percolating to considerable depths or that a mass of soil having a much larger cross-sectional area than the cross-sectional area of the inclosed cylinder is acting as a reservoir for the percolating water. Since evidence indicates percolation through the soil and underlying strata takes place largely through water passageways which are often interconnected, the cumulative infiltration measured by this method is believed not a measure of the cumulative capacity of the soil corresponding to an area of land surface equal to the cross-sectional area of the soil cylinder, but represents the approximate storage capacity of the cylinder and an undefined adjacent soil mass below the base of the tube into which the water moves laterally, as well as downward, as soon as it percolates below the obstruction offered by the casement. The enlarged wet area observed at the base of the excavated tubes is positive proof that the percolating water spread laterally to some extent.

The character of the pore space contributing to soil permeability advanced in explanation of the infiltration rates obtained is supported by a variety of evidence. The high infiltration rates in the first 5 minutes is evidence the first few inches of the surface is highly permeable when the soil is dry.

It is assumed that high initial infiltration rates can be attributed to water entering the loose, granular, surface soil, filling the voids to a depth of a few inches almost immediately. It is believed continuing high rates are dependent upon cracks or other water passageways in the cylinder which connect with others below and outside the tube. The high rates maintained over a relatively long time, it appears, can only be explained by assuming that some of these water passageways are rather stable under the conditions of the measurement and connected to an underground reservoir of large capacity. The so-called reservoir capacity is believed to consist of interconnected cracks or water passageways which underlies a rather extensive surface area. The low rates attained in the cylinders of cultivated land and in three cylinders of meadow land before the moisture deficit of the soil has been satisfied probably can be attributed to a lack of interconnected water passageways through the cylinder, or to an abnormally large reduction in the size of the water passageways due to the swelling of the soil which takes place upon wetting.

The smaller cumulative infiltration measured on the cylinders of meadow land incased by the long tubes compared to those incased by the short tubes is attributed to the effect of the tube wall in cutting off water passageways. The probability that a considerable number of water passageways will be intercepted by the tube as it is forced vertically into the soil is obvious when it is recognized that these passageways do not always lead vertically into the soil but may proceed at an angle or be tortuous in character.

Assuming that the tube wall does intercept water passageways and that all water passageways are not interconnected within the soil mass bounded by the tube, the tube walls may block the further downward movement of water through the passageways cut off by the tube. Other water passageways existing in the subsurface may be directly connected to the surface only at a point outside of the tube and consequently rendered ineffective as water passageways for transmitting water through the soil incased by the tube. The tube wall will thus tend to cause infiltration determined on an incased cylinder of soil to be lower than if water was applied to an equal surface area in the absence of a tube. On the other hand, if some water passageways are continuous through the soil cylinder incased by the tube, the water transmitted through the cylinder would have an opportunity to spread into surrounding passageways. This would tend to give an abnormally high measure of infiltration.

It is believed that the extent to which depth of incasement will modify infiltration data obtained by this method will depend upon the character of the pore space responsible for percolation and the sequence of permeability factors in the soil profile. Standardization in length of casement does not overcome this objection since soil characteristics governing permeability would be expected to modify the influence which the casement would exert, thus the rates obtained for different soils are not strictly comparable and the method cannot be depended upon to furnish a reliable index of infiltration characteristics.

The question may be raised as to the extent which the casement will modify percolation as the cross-sectional dimensions of the soil cylinder is increased. While the effect of this factor was not included in our study it is expected it would be proportional to the ratio of the perimeter of the casement and the surface area to which water is applied. Consequently, the larger the cross-sectional area of the soil cylinder, the less should be the modifying influence of the casement.

Evidence that earthworms were active in some of the cylinders of meadow land was observed about a week before infiltration measurements were made the second time. The soil cylinders were maintained in a moist condition for 41 days between the first and second measurement. The presence of earthworms was confirmed when the cylinders were excavated and the soil removed from the tubes. Normally, under moisture conditions which existed in the area, earthworms are not found above the 4-foot depth. It is believed the earthworms in the tubes moved in from the adjacent wetted area below the base of the tubes, consequently the numbers found cannot be considered an index of the density of the earthworm population in the area.

Infiltration rates were materially higher in the cylinders containing earthworms than the rates at the completion of the first determination. These higher rates persisted throughout the measurement, a period of 10 hours (Table 4). It is of interest to note that the degree to which the infiltration rate increased corresponded to the number of large earthworms in the soil cylinder. No earthworms were found in the cylinders of cultivated land and it has been observed that while

earthworms are quite numerous in the Houston black clay supporting a grass cover, they are found infrequently in cultivated areas.

TABLE 4.—*Effect of earthworm activity on infiltration rates.*

Soil cylinder	Infiltration, surface inches per hour								Earthworms in cylinders*	
	Initial run	Wet run							Large	Small
Meadow Land										
	46–48 hrs.†	5 min.	5 min.–1 hr.	1–2 hrs.	2–4 hrs.	4–6 hrs.	6–8 hrs.	8–10 hrs.		
16	3.24	12.24	2.96	6.17	7.30	8.98	7.22	7.04	2	23
15	0.84	12.84	1.92	2.09	2.34	2.52	2.75	2.24	1	20
27	0.46	14.88	2.12	1.74	1.45	1.30	1.30	1.31	1	21
11	0.12	12.48	0.16	0.02	0.10	0.12	0.14	0.14	0	38
25	0.04	7.20	0.35	0.12	0.08	0.08	0.07	0.08	1	9
22	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Cultivated Land										
		0–3 days	3–6 days	6–14 days	14–23 days	23–30 days	30–32 days	32–34 days		
5	<0.01	0.002	0.002	0.003	0.002	0.001	0.001	0.001	0	0
2	0.01	0.002	0.002	0.002	0.002	0.002	0.001	0.001	0	0
3	0.02	0.003	0.004	0.004	0.003	0.002	0.002	0.002	0	0

*Large earthworms 4 inches or longer; small earthworms 2 inches or shorter.
†Data taken from Table 1. The values appearing in this column were obtained 41 days prior to those in the following columns. High moisture content maintained during 41-day interval.

Maintaining cylinders of cultivated land in a saturated condition over a long period of time appeared to reduce infiltration rates. The rates at the end of the 48-hour initial test, however, had already become so low that the further decrease shown may not be significant.

The relative volumes of soil, water, and air in the cylinders were determined in an attempt to provide an explanation of the erratic infiltration behavior of individual cylinders representing a similar land and cover condition. The volumes occupied by the cylinders in their initial relatively dry and their subsequent wet condition were computed from the measured dimensions of the incased cylinders in the two conditions. The apparent density and the percentage by volume of soil, water, and air in the individual cylinders before and after the infiltration determinations are given in Table 5 for the three groups of cylinders, in the order of their increasing infiltration capacities.

A highly significant correlation was found between apparent density and infiltration for the short cylinders. The correlation for the long cylinders was less significant (Table 6). It will be noted that this is the case over a number of selected intervals. This does not infer, however, that the permeability of the cylinders is a function

TABLE 5.—*Comparison of porosity factors at two moisture levels.*

Soil cylinder	Apparent density			Soil, % by volume			Air, % by volume			Water, % by volume			Water content, surface inches		
	Dry	Wet	Diff.	Dry	Wet	Diff.	Dry	Wet	Diff.	Dry	Wet	Diff.	Dry	Wet	Diff.
1*	1.427	1.295	0.132	52.9	48.0	4.9	21.0	15.0	6.0	26.1	37.0	10.9	4.94	6.98	2.04
2	1.326	1.250	0.076	49.1	46.3	2.8	27.2	6.4	20.8	23.7	47.3	23.6	3.95	8.33	4.38
3	1.277	1.214	0.063	47.3	45.0	2.3	29.8	9.3	20.5	22.9	45.7	22.8	3.83	8.06	4.23
4†	1.324	1.277	0.047	49.1	47.3	1.8	27.2	8.0	19.2	23.7	44.7	21.0	4.00	7.81	3.81
5	1.305	1.267	0.038	48.3	46.9	1.4	28.3	4.9	23.4	23.4	48.2	24.8	3.83	8.13	4.30
6†	1.209	1.173	0.036	44.8	43.4	1.4	33.6	7.8	25.8	21.6	48.8	27.2	3.54	8.24	4.70
Av.	1.311	1.247	0.065	48.6	46.2	2.4	27.8	8.6	19.3	23.6	45.3	21.7	4.02	7.93	3.91
11*	1.280	1.230	0.050	48.3	46.4	1.9	29.9	15.1	14.8	21.8	38.5	16.7	3.38	6.21	2.83
12†	1.278	1.239	0.039	48.2	46.8	1.4	30.0	7.2	22.8	21.8	46.0	24.2	3.51	7.64	4.13
13*‡	1.274	1.247	0.027	48.1	47.1	1.0	30.9	10.9	19.9	21.0	42.0	21.0	2.33	7.34	5.01
14*‡	1.226	1.175	0.051	46.3	44.3	2.0	31.5	10.0	22.8	22.2	45.7	23.5	3.25	8.17	4.92
15‡	1.215	1.179	0.036	45.8	44.5	1.3	33.5	21.1	12.4	20.7	34.4	13.7	3.34	5.72	2.38
16‡	1.246	1.209	0.037	47.1	45.6	1.5	31.7	13.1	18.6	21.2	41.3	20.1	3.48	6.97	3.49
17†	1.134	1.082	0.052	42.8	40.8	2.0	37.9	19.4	18.5	19.3	39.6	20.3	3.02	6.52	3.50
Av.	1.226	1.194	0.032	46.7	45.1	1.6	32.2	13.8	18.5	21.1	41.1	19.9	3.19	6.94	3.75
21*	1.438	1.407	0.031	54.3	53.1	1.2	19.8	9.6	10.2	25.9	37.3	11.4	7.91	12.97	5.06
22	1.351	1.297	0.054	51.0	49.0	2.0	26.0	8.3	19.4	23.0	42.7	21.4	7.65	14.77	7.12
23†	1.470	1.449	0.021	55.5	54.7	0.8	19.5	5.4	14.1	25.0	39.7	14.7	8.73	14.03	5.30
24*‡	1.330	1.303	0.027	50.2	49.2	1.0	27.0	9.4	17.6	22.8	41.4	18.6	6.90	15.01	8.11
25‡	1.313	1.299	0.014	49.5	49.0	0.5	28.1	8.3	19.8	22.4	42.7	20.3	7.80	15.05	7.25
26†	1.347	1.328	0.019	50.8	50.1	0.7	26.2	7.4	18.8	23.0	42.5	19.5	7.92	14.88	6.96
27‡	1.315	1.296	0.019	49.6	48.9	0.7	28.0	9.1	18.9	22.4	42.0	19.6	7.78	14.81	7.03
Av.	1.366	1.340	0.026	51.6	50.6	1.0	24.9	8.0	17.0	23.5	41.3	17.9	7.81	14.50	6.69

*Cylinders excavated prior to making infiltration determination.
†Cylinders excavated within a few hours after the completion of the infiltration determination
‡Cylinders used for the computation of field capacity.

of the total porosity without reference to the distribution of this porosity. The fact that the high cumulative infiltration for several individual cylinders was not accompanied by correspondingly low apparent densities is evidence the distribution of the pore space is an important factor. Additional evidence is presented later (Table 8). It is conceivable that the incased soil mass might normally occupy a greater volume when wet than the volume defined by the tube walls. Swelling which would occur upon wetting would be expected in such an instance to compact the soil. If compaction results, Baver (1) has shown the non-capillary pore space will be reduced proportionately more than the total pore space.

TABLE 6.—*Correlation coefficients between volume weights and infiltration.*

Comparison	Correlation coefficients	
	19 inch tubes	38 inch tubes
Volume weight of soil before run with infiltration for:		
First 5 minutes	−0.733	−0.545
First 2 hours	−0.730	−0.730
48 hours	−0.780	−0.506
Volume weight of soil after run with infiltration for:		
Last 2 hours	−0.738	−0.344
48 hours	−0.858	−0.407

Minimum value for significance (19 inch tubes) P=.02 r=.634
P=.01 r=.684
Minimum value for significance (38 inch tubes) P=.10 r=.669
P=.05 r=.754

The initial water content of the cylinders was assumed to be the average moisture content of the samples obtained from the immediate vicinity of the group of cylinders. Consequently, the moisture content of individual cylinders, except the excavated cylinders, is not strictly quantitative. The excavated cylinders indicated the computed moisture content of the soil cylinder differed from the true value by not over 1.0% moisture by weight.

The elevation of the soil surface in the tubes increased, without exception, upon wetting. The difference in the apparent density of the dry and wet cylinders reflects the change in volume resulting from swelling.

The field capacity, or water held against free drainage, was computed for the individual cylinders of meadow land through which there was percolation. The degree to which drainage was unimpeded probably is reflected by the volume of percolate (Table 1). Limiting computations of field capacity to cylinders which permitted some drainage seems necessary as it constituted the only evidence that the gravitational water had functional freedom and even where considerable percolation occurred this probably did not constitute evidence that entrapped gravitational water is not present in some

portions of the cylinder or that all of the cylinder was wetted to capacity. The field capacity so determined was somewhat variable, but the average values were in fair agreement with field moisture determinations made in the locality during prolonged wet periods.[6]

The difference in the water content of the soil cylinders excavated immediately and those allowed to drain in place for 13 days was not significant, as will be seen by comparing the water content of cylinders 12 and 17 with cylinders 11, 15, and 16, and cylinder 26 with cylinders 25 and 27, in the wet condition (Table 5). A comparison of the water content of cylinders 11, 15, and 16, with cylinders 13 and 14, and cylinders 25 and 27 with cylinder 24, contrary to expectations, shows no consistent difference in the quantity of water held against gravity when the cylinder was continuous with underlying material and when it was broken as is the case with the excavated cylinders.

Periodic determinations of infiltration and percolation with excavated soil cylinders were made for two long and two short cylinders of meadow land and one cylinder of cultivated land (Table 7). After 48 hours no percolation had taken place through one long soil cylinder of meadow land or through the cylinder of cultivated land, although water was applied continuously. In the soil cylinders through which percolation did take place it occurred within 3 minutes or less from the time water was applied, indicating that they contained some water passageways which offered little resistance to the movement of water and that percolation is dependent largely on these water passageways. The quantity of water which had entered the soil at the time percolation began was considerably less than required to bring the soil to saturation. It is of interest to note that at the end of the test, but before gravitational water had an opportunity to drain from the cylinders, approximately 10% or more of the pore space was still occupied by air. It is not believed that this can be attributed entirely to interference which the cylinder walls may have exerted but to a condition normally present in the soil under field conditions.

TABLE 7.—*Soil moisture content in relation to percolation and saturation of soil cylinder.*

Soil cylinder	Time required for percolation to begin, min.	Time at which sufficient water had been added to have completely filled the pore space of the cylinder, min.	Percentage initial saturation	Percentage saturation attained at time shown in column 3	Percentage saturation finally attained
1	No percolate	———	55.4	—	71.1
21	No percolate	———	56.7	—	79.5
24	3 min.	24 min.	45.8	80.1	87.9
13	3 min.	13 min.	40.5	75.1	87.5
14	2½ min.	12 min.	41.3	70.2	90.5

[6]Unpublished soil moisture data.

In the cylinders through which percolation took place the pore space occupied by air was increased as a result of drainage. The increase in the pore space occupied by air is assumed to be the pore space effective in transmitting water (Table 8).[7]

TABLE 8.—*Pore space effective in transmitting water at the completion of a 48-hour infiltration measurement.*

Soil cylinder	Percentage of total pore space			Infiltration, surface inches per hour, 46–48 hours
	Pore space occupied by air at maximum water-holding capacity attained	Pore space occupied by air after drainage of gravitational water	Pore space transmitting water*	
1	28.9	28.9	0.0	<0.01
21	20.5	20.5	0.0	<0.01
24	12.1	18.5	6.4	0.05
13	12.5	20.7	8.2	0.39
14	9.5	17.9	8.4	0.98

*Assuming that the increase, due to drainage, in the pore space occupied by air is the pore space effective in transmitting water.

CONCLUSIONS

The great variation in infiltration as measured on soil cylinders representing a given land condition can likely be attributed to three factors, *viz.*, the inherent variation in the permeability of the soil, the extent to which this permeability is rendered ineffective by the tube wall acting as a barrier to water, and the extent of lateral spreading below the tube wall.

The high infiltration rates which persisted in a number of cylinders for a considerable time indicate a continued high permeability in these cylinders, however, the amount of water passing through the cylinders cannot be considered to reflect the reservoir capacity of the cylinders and the underlying material of equal cross-sectional area.

Earthworm activity was found to increase infiltration appreciably when conditions are such that earthworms extend their burrows to the surface.

The permeability of the soil cylinders is not a function of the total porosity of the cylinder without reference to the distribution of that porosity but is dependent almost entirely on water passageways or zones of above average porosity.

Prolonged wetting was not effective in displacing all air from the soil pores, but in every case an appreciable percentage of the pore space continued to be occupied by air.

The pore space in Houston black clay effective in transmitting gravitational water is limited to a small percentage of the total pore space and is not measured by the space occupied by air at field capacity.

[7]It is to be noted that the infiltration rates obtained during the latter part of the run correspond in order though not in magnitude with this increase in pore space.

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READING FOR SOIL SCIENTISTS, TOGETHER WITH A LIBRARY[1]

CHARLES E. KELLOGG[2]

I. READING

READING is largely a matter of habit. Such habits, like others, are usually acquired early in life, although frequently in later years. They may be good or bad and, like all habits, may be changed for better or worse as time goes on. The habit of much reading is not necessarily a virtue; it may be simply an escape from some more unpleasant alternative, such as helping with evening chores or the effort of thinking on one's own account.

A lot is said about "purposeful" reading as contrasted to reading for "pleasure". These categories really do not mean much, however, because people do not agree on the meaning of either "purposeful" or "pleasure". Some people get pleasure from following the simple intricacies of a detective story while others, who detest detective stories, may enjoy a book like Spengler's *Decline of the West*—are hardly able to lay it down. One of my friends finds great joy in sitting up late before the fire and reading Pliny and Horace in the original. Most of us wouldn't.

Most people will not read much unless they derive a certain satisfaction from it. Some get satisfaction from the very music of word combinations. Others enjoy reading about places or experiences that recall to themselves pleasant places they have seen or pleasant experiences they have had. The important escape or "ivory tower" motive has been mentioned. Some people get satisfaction from learning, and reading offers one very important way of realizing this satisfaction. Most of those who like to read probably get more or less satisfaction in each of these ways.

For people of small or moderate means, reading offers the only practical method of becoming acquainted with the world, the nature of society, and the development of our culture. But then, some one may ask, why should anyone want to know these things? This is a question for the metaphysician; I shouldn't even attempt an answer. If we assume that one has this desire, whatever the reason, he has the first requirement for a general reader—the desire to know something about something. At the start, the objective may be very narrow, but it is liable to grow, first in one field and then from one to another. It seems as if the learning process, when stimulated from within, develops rapidly into a hopeless race. The more one reads and learns, the more things one finds that he wants to learn more about, because progress in one field depends upon others, and these, in turn, upon still others. As the process continues, new relationships appear that must be explored. One may begin in soil science, but if he follows it through he will dig into Aristotle, Shakespeare, Voltaire, and hun-

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dreds more before he is finished. Really, he never gets finished. A general reader is always behind with his reading.

It is rather a knowledge of relationships that the general reader seeks, not facts *per se*. He reads to enlarge his own experience. The encyclopedic mind, with each fact carefully insulated from every other one, does not satisfy the purpose we have assumed for our general reader.

As the reading goes on, understanding usually grows. In all writing the author assumes certain knowledge on the part of the reader. In especially serious books this demand on the reader may be great and an understanding of the author's work depend upon a broad knowledge of the classics of science and literature. A simple or even indirect reference to a historical or fictional character, place, or event is often used to convey some entire thought. Now, of course, one doesn't need to read such books. There are a good many others available that require but little background, very little indeed. But these are not likely to serve the purpose of our general reader, at least not entirely. This thought leads me to mention another purpose, or rather compensation, that reading has for the general reader. Widely read people seldom get lonesome; even when they have no books by them they have a rich storehouse of memories. A widely read old man on his deathbed was asked if he would say a last word to his waiting friends. He simply turned his head toward his books and said softly, "Goodbye, my friends".

The development of taste in reading is not for me to discuss except that I should like to emphasize the importance of internal stimulation. There is no great need to worry about not having read *Anthony Adverse*, *Rebecca*, or even *Gone with the Wind*. Not that these may not be good books, well worth reading perhaps, but because if one tries to "keep up" with all the current literary thrillers, so much reading will be required, since there is constantly a fresh crop each year, that the average ones of us will have time for nothing else. Except for professional critics who must, few widely read people, general readers, even attempt to keep well abreast of the current literature. Probably few if any soil scientists could possibly do so, and become general readers at the same time.

Then again some authors—even many of those widely acclaimed—may not interest us. They just are not somehow *simpático*. Perhaps we "can't get our teeth into the stuff". It is better to pass them by than to waste time that might be spent to better advantage on others. We must be careful, however, that we give the author a fair trial and not dismiss as adults what we, perhaps, could not understand as children. Here must be mentioned the very worst crime of many professional pedagogues. Frequently they take a great masterpiece, written for mature adults to read as a whole, pick it into unintelligible, undigestible pieces, and then serve it up, bit by bit, to young people who shouldn't be expected to understand it under normal conditions, let alone after mutilation. Especially when the pieces are garnished with an abundance of obvious gushiness, the youngster stands in a fair way of developing a thorough hatred of the classics—a feeling that may remain for the rest of his life. Names like Thackeray,

Shakespeare, and Emerson strike terror to his heart. And what a pity! For regardless of the purpose of reading—whether for education, as an escape, for amusement, or just to waste time—the classics are the best for it. Not because they are classics, but for the reasons that made them classics.

If for some reason one has this desire that makes a general reader, and it gets a real hold over him in the more aggravated form, he will want to look into all the various departments of knowledge. Not only will he become a reader, but a rapid reader. He will find that even in the best books a great deal may not be worth much time, especially since there will be so much ground to cover, so many more books ahead of him. Most widely read people are very rapid readers. The reading process is too painful to the slow reader; he would rather do something else. Unfortunately, many young people do not develop reading habits aside from their school books. Naturally, one reads those books upon which he may be examined more slowly, and if this kind of reading sets his pace, determines his reading habits, he will never become a wide reader. A bit of experience as a teacher I would like to suggest to other teachers trying to interest students in general reading, *viz.*, recommend books of special interest to the student (not the teacher) but don't ask the student about them afterward.

What should be the reading habits of a soil scientist? Each one will, of course, need to answer this question for himself. These habits will need to be adjusted to his other habits. If they are not, the answer always is, "I should do more reading; I would like to, but I haven't the time". Of course, this is rarely, if ever, true. The truth is simply that there are other things he would rather do. Then there is eye strain, the real kind and the convenient kind. Although a few suggestions follow, I have no illusions regarding either their applicability or their adoption.

First, let us assume that the prospective soil scientist has, for some reason that we cannot go into here, a desire to know much about soil science, its relationship to other sciences, and how his own work may contribute to the welfare of the society of which he, as an individual, is a part. He realizes that there are three great classes of relationships and that somehow he must realize a partial understanding of all three: (1) The relationship of facts to facts, the field of science; (2) the relationship of the man to the facts, the field of art; and (3) the relationship of man to man, the field of justice and morals. He strives to make his knowledge symmetrical and to develop completeness as an individual in society, as a citizen of the world as well as a specialist in soils. He finally comes to the realization that knowledge is, after all, one great body, not departmentalized, but a huge jewel with many facets.

It would be my thought that this scientist attempts to keep himself reasonably well informed upon current research in his own field and closely related fields. He doubtless receives regularly the publications of the Soil Science Society of America, the International Society of Soil Science, and the American Society of Agronomy. He also notes the important periodicals dealing with soil science and some of the closely allied fields. Without doubt he reads regularly the publications

of the American Association for the Advancement of Science. From these he proceeds to important monographs and books that have a special interest to him.

In more general fields he examines a few good newspapers and current magazines that include essays of interest and from which he is able to keep in touch with the several phases of our social and intellectual life. From these points of departure, he goes where he must to accomplish his purpose. Time and time again he needs to build in background material from the classics and from elementary books of many sciences. He may even read some books on the following list, or on better lists.

Our soil scientist has become a general reader!

II. A LIBRARY FOR A SOIL SCIENTIST

The following list of books has been prepared with the thought of suggesting a few that might be of value to one who is beginning soil science as a major line of interest. For a satisfactory concept of the place of science in contemporory life it is essential to have some appreciation of the nature and development of society and the ideas of people. These ideas have been expressed in novels, dramas, stories, and poems as well as in essays. Many kinds of people, in different places and at different times, have contributed their bit to the expression of our culture.

No one person, or group of persons, can pretend to make a very satisfactory reading list for another person. For one thing, such a list should include only those books with which the compiler is familiar. No one has been able to read all the good books, and all of us read a large number of mediocre ones for each one that appeals to us as exceptional, or even good. The list of books that follows comprises a few that its compiler has thought to be of special value to him. Many have been omitted that others might include simply because, for some reason, they did not appeal to this compiler. Unfortunately, there are many, many other good books that the compiler has not read—or even heard of for that matter. A few items have been omitted because of the difficulty of obtaining accurate versions in English, and a few for other reasons.

The titles are arranged in groups in order to distinguish roughly the technical books from those of more general interest. Of particular importance to the beginner in science are those works dealing with the philosophy of science and with the fundamental nature of the method, included in section IV. No significance whatever is to be attached to the order in which the titles appear in the list. Dates and other data are given only where helpful to identify a particular edition.

The compiler of this list is fully aware that it is open to serious criticisms on several grounds, including those of personal prejudice and narrowness of scope. Much better lists might exclude some titles and include many additional ones.

I. SOIL SCIENCE

1. Soils, their origin, constitution, and classification. G. W. Robinson. Murby. 1936.
2. Mother earth. G. W. Robinson. Murby. 1937.
3. Soil conditions and plant growth. Sir E. J. Russell. Longmans. 1937.
4. The soil. Sir A. D. Hall. Dutton. 1931.
5. The physical properties of the soil. B. A. Keene. Longmans. 1931.
6. The scientific study of the soil. N. M. Comber. Longmans. 1936.
7. Soils. E. W. Hilgard. Macmillan. 1906.
8. Soil fertility and permanent agriculture. C. G. Hopkins. Ginn. 1910.
9. Die Typen der Bodenbildung. K. Glinka. Borntraeger. Berlin 1914. (Also in English translation under the title "The great soil groups of the world and their development". C. F. Marbut. Ann Arbor. 1927.)
10. The evolution and classification of soils. E. Ramann. Translated by C. L. Whittles. Heffer. 1928.
11. Soil and civilization. Milton Whitney. D. van Nostrand. 1925.
12. International Congresses of Soil Science. Proceedings. 1st. Washington, 1927, 4 v.; 2d. Moscow, 1930, 6 v.; 3d. London, 1935, 3v.
13. Soils of the United States. C. F. Marbut. In atlas of American agriculture. Washington. 1935.
14. Soils and men. 1938 Yearbook of Agriculture.
15. The soils of Tennessee. C. F. Vanderford. Tenn. Agr. Exp. Sta. Bul. 10. 1897.
16. Pedology. J. S. Joffee. Rutgers. 1936.
17. The soil, its nature, relations and fundamental principles of management. F. H. King. Macmillan. 1916.
18. Manures and Fertilizers. Wheeler. Macmillan. 1913.
19. The group of papers covering the development of pedology in Russia prepared for the First International Congress of Soil Science. Leningrad. 1925. (In English.)

II. RELATED SCIENCES

20. Climate. W. G. Kendrew. Oxford. 1930.
21. The climates of the continents. W. G. Kendrew. Oxford. 1938.
22. Rocks, rock-weathering, and soils. G. P. Merrill. Macmillian.
23. Colloids. H. R. Kruyt. Wiley.
24. Outlines of theoretical chemistry. Getman and Daniels.
25. Outlines of biochemistry. Gortner. Wiley. 1938.
26. Principles of soil microbiology. Waksman. Baltimore. 1932.
27. Plant physiology. E. C. Miller. McGraw-Hill. 1938.
28. Plant physiology. N. A. Maximov. McGraw-Hill. 1938.
29. Crop production. Hughs and Henson. Macmillan.
30. Fundamentals of fruit production. Gardner, Bradford and Hooker. McGraw-Hill.
31. Elements of the differential and integral calculus. Granville. Ginn.
32. The determination of hydrogen ions. W. M. Clark. Williams & Wilkins.
33. The data of geochemistry. F. W. Clarke. U. S. G. S. Bul. 770. 1924.
34. Analytical chemistry. Treadwell and Hall. Wiley. 1930.
35. Production organization. Black and Black. Holt. 1929.

36. Race, sex, and environment; a study of mineral deficiency in human evolution. J. R. de la H. Marett. Hutchinson. London. 1936.
37. The formation of vegetable mould, through the action of worms with observations on their habits. C. Darwin, New York. 1882.
38. Geomorphology—A. K. Lobeck.

III. EARLY AGRICULTURE

39. Terra, a philosophical discourse of earth. John Evelyn.
40. Sylva, or a discourse on forest trees. John Evelyn.
41. Husbandry (De re rustica) L. J. M. Columella (written about 60 A. D.) English translation 1745.
42. Travels in France. Arthur Young.
43. Letters from an American farmer. J. Hector St. John Crevecoeur.
44. Geology and agriculture of Mississippi. E. W. Hilgard. 1860.
45. An essay on calcareous manures. Edmund Ruffin. 1852.
46. Roman farm management: a translation of Cato and Varro. "A Virginia Farmer". MacMillan. 1913.
47. Vegetable staticks. Stephen Hales. London. 1731–33.
48. The horse hoeing industry. Jethro Tull. London. 1731.
49. The natural laws of husbandry. Justus von Liebig. 1863.
50. The elements of agriculture. M. Duhamel du Monceau.
51. The Georgics. Virgil.

IV. SCIENCE: HISTORY, MEANING, METHOD, AND PHILOSOPHY

52. The nature of things. Lucretius. (Translation by Munro or Leonard).
53. History of the inductive sciences. William Whewell.
54. The advancement of learning. Francis Bacon.
55. The order of nature. L. J. Henderson.
56. Foibles of insects and men. W. M. Wheeler.
57. The biological basis of human nature. H. S. Jennings.
58. The universe in the light of modern physics. Planck.
59. The grammar of science. Karl Pearson.
60. The discourse on the method. Descartes.
61. Physical forces of nature. Faraday.
62. The chemical history of the candle. Faraday.
63. The nature of the physical world. A. S. Eddington.
64. Conservation of force and other essays. Helmholtz.
65. Introduction to mathematical philosophy. Bertrand Russel. London. 1919.
66. A system of logic. J. S. Mill. (Eighth or subsequent edition.)
67. The analysis of matter. Bertrand Russell.
68. The biology of death. Raymond Pearl.
69. Civilization and climate. Ellsworth Huntington.
70. The scientific outlook. Bertrand Russell.

V. PHILOSOPHY, CONDUCT OF LIFE, HISTORY, ETC.

71. The decline of the West. Oswald Spengler. Knopf.
72. The development of the understanding. Spinoza.
73. Essays and journal. Emerson.
74. Thus spake Zarathustra. Nietzsche.

75. The dialogues. Plato.
76. Sexual life of savages. Bronislaw Malinowski.
77. The tale of a tub. Jonathan Swift.
78. The Savoyard vicar. Rousseau.
79. The Bible.
80. The Dabistan, or school of manners. Masham Fani.
81. The golden sayings of Epictetus.
82. Counsels and maxims. Schopenhauer.
83. Liberty. J. S. Mill.
84. The Koran.
85. The American language. H. L. Mencken. Knopf. 1936.
86. The prince. Machiavelli.
87. Micromegas. Voltaire.
88. The Anti-Christ. Nietzsche. (Trans. by H. L. Mencken.)
89. The history of civilization in England. Buckle.
90. In praise of folly. Erasmus.
91. The eulogies, etc. Ovid.
92. Letters. Pliny the Younger.
93. Goodbye to western culture. Norman Douglass.
94. History of art. Elie Faure.
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98. Democracy in America. Alexis C. H. C. de Tocqueville.
99. Essays. Montaigne.
100. The engineers and the price system. Veblen.
101. The theory of the leisure class. Veblen.
102. The anatomy of melancholy. Robert Burton.
103. Six rooms make a world. Gove Hambidge.
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106. Democracy in crisis. Laski.
107. Whose constitution? H. A. Wallace.
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111. Madam Bovary. Flaubert.
112. An American tragedy. Theodore Dreiser.
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115. Lorna Doone. Blackmore.
116. The cloister and the hearth. Reade.
117. Don Quixote. Cervantes.
118. Penguin island. France.
119. Heloise and Abelard. George Moore.
120. Jurgen. Cabel.
121. Kristin Lavransdatter. Sigrid Undset.
122. Oliver Twist. Dickens.

123. The life and opinions of Tristram Shandy, gentleman. Sterne.
124. The portrait of the artist as a young man. James Joyce.
125. The brothers Karamazov. Dostoevsky.
126. Shiny night. Beatrice Tunstall.
127. The picture of Dorian Gray. Oscar Wilde.
128. Fräulein Else. Schnitzler.
129. The remembrance of things past. Marcel Proust.
130. Vanity fair. Thackeray.
131. Madamoiselle du Maupin. Gautier.
132. Fathers and sons. Turgenev.
133. The devil's pool. George Sand.
134. Pilgrimage. Dorothy M. Richardson.
135. Look homeward, angel; Of time and the river; The web and the rock; and You can't go home again. Woolfe.
136. Breaking point. Artzibashef.
137. Alexander-platz Berlin. Döblin.
138. The Buddenbrooks. Mann.
139. Sons and lovers. D. H. Lawerence.
140. Arrowsmith. Sinclair Lewis.
141. The world's illusion. Wasserman.
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143. Studs Lonigan. Farrell.
144. Tom Jones. Fielding.
145. Of human bondage. Maugham.
146. War and peace. Tolstoy.
147. Anna Karenina. Tolstoy.
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149. Jude the obscure. Hardy.
150. Green mansions. W. H. Hudson.
151. Maria Chapdelaine. Hémon.
152. The pleasant memoirs of the Marquis de Brandomin. Valle-Inclau.
153. Indian lilies. Sudermann.
154. The book of the thousand nights and one night. Burton translation.
155. Messer Marco Polo. Byrne.
156. Candide. Voltaire.
157. The Princess of Babylon. Voltaire.
158. Stories. De Maupassant.
159. Stories. D. H. Lawrence.
160. Stories. Poe.
161. The monk and the Hangman's daughter. Bierce.
162. Stories. Andreyev.
163. Stories. Katherine Mansfield.

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164. The life of Washington. Hughs.
165. The life of Samuel Johnson. Boswell.
166. The romance of Leonardo da Vinci. Merejkowski.
167. Pepys' diary.
168. John Evelyn's journal.
169. Figaro: the life of Beaumarchais.

170. Confessions. Rousseau.
171. The memoirs of Casanova.
172. The autobiography of Benvenuto Cellini.
173. Franklin. Faÿ.
174. O Rare Ben Jonson. Steel.
175. The education of Henry Adams. Henry Adams.
176. The life of Robert Burns. Catherine Carswell.
177. Leonardo da Vinci. Antonina Vallentin.

VIII. DRAMA AND POETRY

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179. Poems. T. S. Elliot.
180. Adonias, The hymn of Pan, Ode to the west wind, etc. Shelley.
181. The rime of the ancient mariner, etc. Coleridge.
182. The land. V. Sackville-West.
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184. Sonnets from the Portuguese, A musical instrument, etc. E. B. Browning.
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186. The deserted village. Goldsmith.
187. Lochinvar. Scott.
188. The realm of fancy, Ode to melancholy, The eve of St. Agnes, etc., Keats.
189. The marriage of Heaven and Hell, etc. William Blake.
190. Rubaiyant of Omar Khayyam. Fitzgerald. Fifth edition.
191. Robyn Hode.
192. Elegy written in a country churchyard. Grey.
193. The song of Roland.
194. Hermann and Dorothea, etc. Goethe.
195. Cotter's Saturday night, etc. Robert Burns.
196. The sonnets. Shakespeare.
197. The raven, etc. Poe.
198. The torch bearers. Noyes.
199. Aeneid. Virgil.
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202. Figs from thistles, etc. Edna St. Vincent Millay.
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204. The sunken bell. Hauptmann.
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217. Cyrano de Bergerac. Rostrand.
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EFFECT OF SOIL TREATMENT AND GRAZING MANAGEMENT ON THE PRODUCTIVITY, EROSION, AND RUN-OFF FROM PASTURE LAND[1]

C. A. Van Doren, W. L. Burlison, L. E. Gard, and R. F. Fuelleman[2]

THIS paper presents preliminary results of an experiment being conducted at the Dixon Springs Soil and Water Conservation Experiment Station, located in Pope County, Ill. The station is in the lower Mississippi loess area, comprising 10 to 12 million acres of land in Illinois, Indiana, Kentucky, Tennessee, Arkansas, and Missouri and characterized by silt loam soils badly leached and seriously eroded (1).[3] Existing grazing management and lack of soil improvement practices by farmers are contributing to further depletion of soils of the area.

The general productivity of soils in this area is low. The average yield of 28 crops of wheat on the Elizabethtown Experiment Field on untreated plots during the period 1936–39 was 4 bushels per acre (2). The Elizabethtown field is located on a similar soil type.

The field at Dixon Springs on which this study was established had been used for hay or pasture during the previous 25- or 30-year period. An occasional corn crop was grown on the field when the pasture vegetation became undesirable and badly infested with weeds. Soil tests which were made before treating the plots indicated a need for 3 to 4 tons of limestone. Available phosphate in the soil was low according to the field test.

The objectives as formulated for study are to determine the effect of two rates of grazing, moderate and intense, and the effect of soil treatment, limestone and phosphorus in combination as against no treatment, on water retention, erosion resistance, and forage values of an uncultivated plant cover.

METHODS

Four grazing plots, each ⅓ acre in size, have been established, all located on approximately an 8% slope with a southwest exposure. Records have been secured since the summer of 1938 from plots representing four different combinations of soil treatment and grazing management as indicated below.

Soil Treatment	Grazing Management	Plot No.
Lime, phosphate	Intensive	1
Lime, phosphate	Regulated	2
None	Intensive	3–4
None	Regulated	5

[1]This study is being conducted as a cooperative project between the Illinois Agricultural Experiment Station, Urbana, Ill., and the Soil Conservation Service, Office of Research. Received for publication August 12, 1940.

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[3]Figures in parenthesis refer to "Literature Cited", p. 887.

These plots were treated and seeded during September 1936. After the ground was plowed, fertilizers were applied and were then well mixed into the surface soil with a disc and a spike tooth harrow. Treated plots received limestone applied at the rate of 3½ tons per acre, rock phosphate at 1,000 pounds per acre, and 32% superphosphate at 300 pounds per acre. An additional application at the rate of 150 pounds per acre of 32% superphosphate, or its equivalent, was applied by top dressing in the spring of 1939.

A pasture seed mixture containing orchard grass, 5 pounds; Kentucky bluegrass, 2½ pounds; redtop, 4 pounds; timothy, 2 pounds; sweet clover, 2 pounds; and alsike clover, 1½ pounds per acre, was used in the fall. White clover, 2 pounds; sweet clover, 3 pounds; and Korean lespedeza, 5 pounds per acre were seeded in the spring.

Run-off plots 70 by 14 feet in size are located within each ⅓ acre grazing plot (Fig. 1). Wooden plot walls direct the run-off from the plot into measuring equipment which is located outside of and adjacent to the boundaries of the grazing unit. From the collecting trough at the lower end of the plot the water is carried through a 4-inch iron pipe to the measuring equipment. The type of silt box, screens, divisor unit, and tank used is shown in Fig. 2. The divisor unit has been described by Geib (3).

As soon as possible after each rain, the run-off was removed from silt boxes and tanks and weighed. Samples for dry matter determinations were taken in triplicate from both silt boxes and tanks.

Composition and density of vegetation were determined at intervals of 30 to 45 days throughout the 1938 and 1939 grazing seasons by the vertical point quadrat method. Twenty randomized readings of 10 points, totalling 200 readings, were made on each ⅓ acre plot in 1938, and similarly 40 readings of 10 points were made in the 1939 season.

Seasonal forage yields for 1939 were calculated on the basis of vegetation harvested from five wire-cage enclosures per plot. The type of cage used, which is 3 feet 4 inches on each side, is shown in Fig. 1. Sample areas were located by randomization and the cages were moved at intervals of from 30 to 45 days during favorable growing periods. The protected areas were clipped previous to each grazing period. At the end of the grazing period vegetation on the protected areas was harvested, as well as the vegetation on similar sized unprotected areas. Yields were expressed in pounds per acre of oven-dry forage.

Yearling ewes were used as grazing animals. Pasture days of grazing were recorded in 1938 and 1939. Amounts of gain or loss in weight of sheep also were determined in 1939. The two degrees of intensity of grazing were determined by the amount of cover available for consumption by livestock. The intensively grazed plots were pastured closely or severely throughout the season. The plots on which regulated grazing was practiced were grazed moderately and the vegetation was maintained at a height of approximately 3 to 4 inches.

RESULTS

FORAGE YIELDS AND COMPOSITION OF STANDS FOR 1939

Although these plots were seeded in 1936, installations for measuring soil and water losses were not completed until July, 1938; and sheep for grazing the plots were not available until the summer of 1938. The plots were cut for hay in 1937.

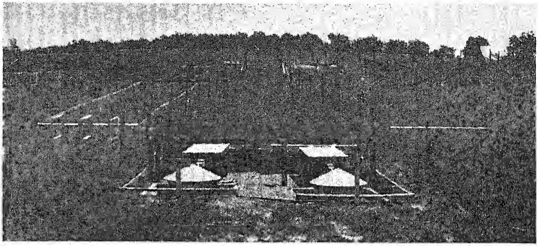

FIG. 1.—Run-off plots and measuring equipment for two 1/3 acre grazing areas. Plot 1, intensively grazed, in 1938; plot 2, grazing regulated. Photographed May 10, 1939.

The amount of vegetative cover on the treated land on which regulated grazing was practiced was from three to four times greater

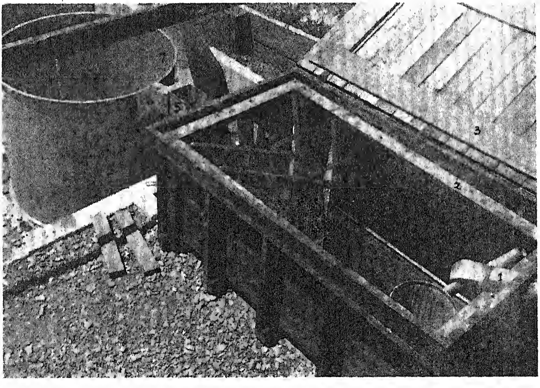

FIG. 2.—Measuring equipment used for determination of soil and water losses from pastured plots. (1) Iron pipe, 4 inches in diameter, through which run-off flows from collecting trough at lower end of plot to silt box. (2) Silt box, 2 feet deep, 3 feet wide, and 6 feet long. These boxes have been lined with metal since photograph was taken. (3) Cover for silt box. (4) Screens for removing trash from run-off before entering divisor unit. The first or nearest screen has a 2-mesh wire cloth, the second has an 8-mesh wire cloth. (5) Multislot divisor unit. The five slots are each 4 inches high and 1/2 inch wide. (6) Small metal flume to carry run-off from center slot of divisor storage tank. Run-off from other four slots is discarded. (7) Metal storage tank, 4½ feet in diameter and 4 feet high.

TABLE 1.—*Average yield of forage per acre, composition and density of vegetation as influenced by soil treatment and grazing management, Dixon Springs Soil and Water Conservation Experiment Station, 1939.**

Sample method	Plot 1, treated, intensively grazed			Plot 2, treated, regulated grazing			Plots 3–4, not treated, intensively grazed			Plot 5, not treated, regulated grazing		
	Apr. 26	June 26	Aug. 4	May 15§	June 26	Aug. 4	Apr. 26	June 26	Aug. 4	Apr. 26	June 26	Aug. 4
Protected areas, lbs.	674	1,322	1,340	1,383	1,557	603	322	1,316	945	—	1,713	632
Sum of protected areas, lbs.	674	1,996	3,336	1,383	2,940	3,543	322	1,638	2,583	—	1,713	2,345
Grazed areas, lbs†	—	535	792	—	2,092	2,204	—	357	1,196	—	—	1,882
Species‡												
Grasses:												
Bluegrass, %	9	6	4	13	13	7	4	1	0	2	0	Trace
Redtop, %	17	10	4	21	18	5	18	8	1	19	26	3
Timothy, %	13	4	1	15	5	0	2	Trace	0	4	Trace	0
Orchard grass, %	8	4	1	11	11	5	1	1	Trace	0	0	Trace
Legumes:												
Alfalfa, %	Trace	0	0	Trace	0	0	0	0	0	0	0	0
Alsike clover, %	0	0	0	0	0	0	0	0	0	0	0	0
White clover, %	1	2	1	1	1	1	0	1	0	0	0	0
Lespedeza, %	1	4	1	5	25	33	Trace	3	2	1	9	5
Sweet clover, %	0	0	0	0	1	0	0	0	0	0	0	0
Weeds, %	1	41	46	1	9	11	11	49	61	11	40	44
Bare ground, %	25	18	18	8	3	4	36	22	9	33	18	6
Dead vegetation, %	25	11	24	25	14	34	28	15	27	30	7	42

*Yield of forage is expressed as an average of five samples, each from an area 3 feet 4 inches square.
†Samples were taken at random from within the 1/3 acre grazed areas.
‡Percentages were obtained by taking 40 readings of 10 points each by point quadrat method.
§Vegetal data taken on April 26.

than on the land intensively grazed (Table 1). On June 26, on plot 1, intensively grazed, 535 pounds per acre were harvested as compared to 2,092 pounds per acre on plot 2, regulated grazing. On August 4, these same plots produced 792 pounds and 2,204 pounds, respectively (Fig. 3).

On land not treated, regulated grazing did not as markedly increase the amount of cover. On August 4, plots 3 and 4, intensively grazed, produced 1,196 pounds per acre as compared to 1,882 pounds per acre on plot 5, regulated grazing (Table 1).

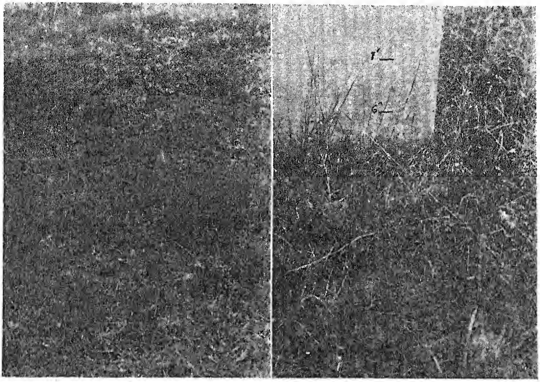

FIG. 3.—Effect of closeness of grazing on vegetation on treated plots. Photographed August 3, 1939. *Left*, plot 1, intensively grazed. Mostly weeds in stand. *Right*, plot 2, grazing regulated. Lespedeza and various desirable grasses in abundance.

Soil treatment increased the total seasonal production of dry forage per acre under intensive grazing. The total seasonal production in 1939 on plot 1, treated, was 3,336 pounds per acre, while on plots 3 and 4, not treated, the total seasonal production was 2,583 pounds (Table 1). With regulated grazing plot 2, treated, yielded 3,543 pounds per acre while plot 5, not treated, yielded 2,345. These results are more significant than indicated by the above figures as the plots which were not treated contained a considerably greater proportion of undesirable vegetation. On August 4, on plot 5, not treated, the vegetational cover contained 44% weeds as compared with only 11% on plot 2. The vegetational cover on the former plot contained only 8% of such desirable plants as lespedeza, bluegrass, redtop, orchard grass, and white clover while plot 2 had a total of 51% of these desirable plants.

RUN-OFF AND SOIL LOSSES

The average rainfall for a 44-year period (1895–1938) at New Burnside, Ill., approximately 12 miles northwest of the station, was 45.47 inches. Normal monthly rainfall in inches during this period was as follows:

Jan.	4.28	Apr.	4.31	July	3.53	Oct.	3.41
Feb.	2.78	May	4.11	Aug.	3.33	Nov.	3.51
Mar.	4.50	June	4.20	Sept.	3.61	Dec.	3.54

Monthly distribution during a given year may be extremely variable, however.

Some of the erosion stations have published data showing the small amount of soil and water lost from pasture land. Hays and Palmer (4) stated that bluegrass sod not mowed, that is, left to grow wild without cutting or pasturing, allowed an annual soil loss of only 0.03 ton and 2.8% run-off. They also reported that plots in grain in 1933 lost 1.6 times as much water as pasture plots; plots in hay in 1934 lost 1.3 times the water lost by the pasture plots; and the plots in corn in 1935 lost 3.0 times as much. Woodruff and Smith (5) reported low soil losses from several pastured areas. They reported that intensive grazing caused a significant increase in run-off as compared with moderate grazing. The vegetation on these plots differed considerably, however, from the vegetation on the Dixon Springs area.

During the 12-month period, July 1938 through June 1939, 37 run-off and soil loss records were obtained. A total of 72 rains causing run-off contributed to the results. Soil losses in pounds per acre from plot 2, which received limestone and phosphate, and on which grazing was moderate in 1938 and 1939, totalled only 330 pounds (table 2). Plot 1, which received limestone and phosphate and was intensively grazed, lost 4,378 pounds of soil per acre. Considering the severe grazing on this plot the total soil loss was small and it indicates the value of pasture vegetation in controlling soil erosion.

Soil losses were also small and were not significantly affected by grazing management on the untreated plots. The soil loss from plot 5, untreated with regulated grazing, was 1,671 pounds per acre which was within the limits of losses from plot 3, 1,292 pounds, and plot 4, 3,684 pounds, untreated with severe grazing. Plots 3 and 4 were both located within the same ⅓ acre grazing area, although plot 4 has slightly less surface soil remaining than plot 3.

Under intensive grazing, the plot which was treated with limestone and phosphate lost more soil per acre than the plot which was not treated, while the reverse was true with moderate grazing. Plots 3 and 4 with severe grazing, which were not treated, lost 1,292 and 3,684 pounds per acre, respectively, as compared with 4,378 pounds from plot 1 which was treated with limestone and phosphorus. This discrepancy was caused in part by the greater abundance of annual grass weeds, particularly the very unpalatable species of aristida on the plots not treated. The vegetal cover on grazing plots 3 and 4 contained 76% weeds and yielded 1,345 pounds per acre of dry forage on August 18, 1938; while that of plot 1, treated

with limestone and phosphate, contained only 42% weeds and yielded 1,180 pounds of dry forage. A year later on August 4, 1939, plots 3 and 4 again contained a larger percentage of weeds and produced a greater amount of dry matter than did plot 1. On the plots with moderate grazing, plot 5, untreated, lost 1,671 pounds while plot 2, treated, lost only 330 pounds of soil per acre.

On land treated with limestone and phosphorus, run-off losses during the 9 months, July through December 1938, and April through June 1939, from intensively grazed land were greater than from land on which grazing was moderate. Plot 1 which was intensively grazed lost 4.82 inches of water or 16.6% of the total precipitation, while plot 2 on which grazing was regulated lost only 0.74 inch of water or 2.6% of the total precipitation. (Table 2). Run-off records were obtained from 43 rains during the 9-month period, and in each instance the loss was greater from the intensively grazed plot. Losses during the 3 months, January to March 1939, were excluded, inasmuch as seepage prevented securing accurate records of run-off.

On the untreated plots, the water lost from plot 5, regulated grazing, 4.68 inches, was between the amount from the intensively grazed plots, plot 3, 3.24 inches, and plot 4, 6.31 inches.

Run-off losses from the untreated plot were greater than from the treated plot when the grazing on both plots was regulated. When intensive grazing was practiced on both treated and untreated plots, the run-off losses were not greater from the untreated land. Run-off plots 3 and 4 were located within the same grazing unit, untreated and intensively grazed. Plot 4 was about 100 feet farther up the slope and had slightly less surface soil remaining than plot 3. The run-off losses from plots 3 and 4 were 11.2 and 21.8% of total precipitation, respectively, as compared to 16.6% from plot 1 which was grazed similarly but which received an application of limestone and phosphorus. Intensive grazing on land not treated favored development of weedy grasses, especially aristida species, which were not eaten by sheep but which retarded soil and water losses.

SHEEP PRODUCTION

Approximately the same number of days grazing was obtained during the second season of grazing in 1939 on treated land when grazing was regulated (198 pasture days) as when intensive grazing was followed (202 pasture days). (See table 3.) A pasture day means the pasturing of one yearling ewe for one day. Considerably fewer days of grazing were obtained on untreated land under moderate grazing (112 pasture days) than under severe grazing management (182 pasture days).

Gain or loss in weights of sheep as well as total days of pasturage were obtained during the second season of grazing (1939). Yearling ewes on the treated plot where grazing was regulated produced a total of 68 pounds gain per ⅓ acre, while on the treated plot which was intensively grazed the ewes produced only 9 pounds of gain.

Regulation of grazing failed to bring about such satisfactory gains on untreated land. The sheep on the untreated, intensively grazed ⅓ acre plot lost a total of 13 pounds during the 182 pasture days of

TABLE 2.—*Run-off and soil loss in run-off from plots as influenced by soil treatment and grazing management, Dixon Springs Soil and Water Conservation Experiment Station, July 1938 to June 1939.*

Date	Rainfall						Plot 1, treated, intensively grazed		Plot 2, treated, regulated grazing		Plot 3, not treated, intensively grazed		Plot 4, not treated, intensively grazed		Plot 5, not treated, regulated grazing	
	Number of rains	Amount, in.	Duration, min.	Intensities per hour, in.			Run-off in % of rainfall, %	Soil loss per acre, lbs.	Run-off in % of rainfall, %	Soil loss per acre, lbs.	Run-off in % of rainfall, %	Soil loss per acre, lbs.	Run-off in % of rainfall, %	Soil loss per acre, lbs.	Run-off in % of rainfall, %	Soil loss per acre, lbs.
				5 min.	15 min.	30 min.										
							1938									
July 12	1	1.24	165	2.40	1.76	1.16	6.5	10	0.4	3	17.8	25	22.4	62	31.1	61
July 17	1	0.71	280	1.20	0.96	0.66	0.9	1	0	1	1.6	3	4.8	3	10.0	5
July 17, 18	4	1.37	435	3.60	2.88	1.52	20.1	28	6.9	20	33.7	64	44.2	65	41.8	91
July 31	1	0.95	450	0.36	0.24	0.24	1.7	1	1.4	1	0.5	1	3.0	1	8.6	2
Aug. 1	1	0.41	195	1.68	1.04	0.60	0.7	2	0	1	3.4	2	16.8	3	17.8	5
Sept. 10	1	1.13	22	4.56	4.32	—	15.9	15	0.8	2	22.5	30	42.7	49	23.3	20
Sept. 13	1	0.91	235	3.12	1.08	0.84	1.4	2	0.2	Trace	6.4	9	14.7	15	8.4	11
Oct. 20	1	1.15	420	2.16	1.12	0.76	0.2	Trace	0	0	0.4	Trace	0.3	Trace	1.3	1
Nov. 4	1	0.37	130	1.56	0.60	0.38	1.6	5	0.3	Trace	0.8	1	1.4	2	0.8	1
Nov. 7	1	0.60	105	1.68	1.12	0.58	8.7	37	1.0	2	10.2	13	20.5	31	18.2	23
Nov. 7	1	0.34	195	0.60	0.24	0.20	1.2	1	0	0	0.6	1	2.4	1	5.0	2
Nov. 18	1	1.70	473	4.32	1.52	0.78	26.3	527	3.2	21	22.5	82	50.7	257	27.4	121
Nov. 23	1	0.27	105	0.36	0.32	0.22	3.7	1	0	0	2.6	1	4.8	1	5.2	1

							1939									
Jan. 28, 29	2	1.08	195	0.48	0.32	0.28	0.5	1	0	0	0	0	0	0	0.6	1
Jan. 29, 30	2	2.21	1,015	0.72	0.52	0.46	102.5	475	18.3	44	91.0	258	91.6	331	96.8	237
Feb. 1, 2	3	1.52	890	0.72	0.48	0.40	143.4	276	21.1	31	96.1	108	165.1	251	125.0	144
Feb. 2, 3, 6, 9, 10	7*	2.55	935	2.28	0.88	0.58	129.4	542	23.1	50	118.8	213	238.8	641	156.1	248
Feb. 14	2*	0.82	430	0.24	0.20	0.18	90.0	24	8.4	1	9.4	2	44.8	26	39.6	9
Feb. 18, 19	2	1.44	650	0.96	0.72	0.64	197.4	588	21.8	22	75.1	84	122.7	311	120.7	153
Feb. 24, 25, 26	2*	0.68	30	—	—	—	150.0	22	0	0	4.9	1	44.7	14	40.4	6
Feb. 27	1*	0.78	—	—	—	—	211.9	351	25.1	10	52.1	25	97.1	216	114.4	110
March 4, 5	3	2.99	1,050	1.80	0.72	0.40	123.1	803	33.1	83	62.4	213	127.9	790	99.9	220
March 10	1	0.77	443	0.48	0.40	0.30	54.5	17	1.3	1	2.6	2	44.2	22	24.7	9
March 11, 12	4	0.49	215	1.20	0.52	0.34	169.4	41	8.2	1	14.3	2	124.5	38	63.3	12
April 5, 6	2	1.79	1,110	0.48	0.36	0.32	7.8	7	0	Trace	6.1	7	11.7	13	7.3	5
April 10	1	0.36	125	1.44	0.72	0.38	8.3	13	0	0	0	0	11.1	14	5.6	6
April 15, 16	3	1.97	445	2.04	1.04	0.96	95.9	205	19.3	18	36.0	39	58.4	157	60.9	75
April 16, 17	2	0.84	380	1.80	0.76	0.38	100.0	92	14.3	8	56.0	30	81.0	109	92.9	63
April 17, 18	3	0.17	265	0.24	0.12	0.06	64.7	4	0	0	0	0	29.4	2	82.4	3
April 20, 21	2	0.33	200	0.48	0.40	0.24	9.1	3	0	0	0	0	27.3	5	24.2	4
May 25	2	0.75	40	2.88	2.00	—	25.3	122	2.7	4	17.3	33	30.7	94	5.3	9
May 27	3	0.35	145	0.84	0.48	0.46	5.7	3	0	0	0	Trace	8.6	4	0	0
June 1	1	0.66	275	0.72	0.40	0.34	1.5	Trace	0	0	1.5	Trace	3.0	2	0	0
June 8, 9	3	0.60	298	1.08	0.52	0.28	1.7	1	0	0	0	Trace	1.7	2	0	0
June 10	1	0.35	30	2.16	1.20	0.68	25.7	41	0	0	17.1	11	34.3	44	5.7	4
June 19	3	0.48	70	1.80	0.72	0.18	6.3	13	0	0	4.2	3	12.5	14	0	0
June 20	1	0.76	60	1.92	1.84	1.00	43.4	104	3.9	6	32.9	29	50.0	94	15.8	9
Total soil loss and run-off per acre:																
For 12 months (July, 1938–June, 1939), lbs.							4,378		330		1,292		3,684		1,671	
Precipitation† and run-off, 9 months (July, 1938 through June, 1939, excluding Jan.–Mar., 1939):																
Total precipitation, inches							29.00		29.00		29.00		29.00		29.00	
Total precipitation (rains causing run-off), inches							20.56		20.56		20.56		20.56		20.56	
Total surface run-off, inches							4.82		.74		3.24		6.31		4.68	
Total surface run-off in % of precipitation, %							16.6		2.6		11.2		21.8		16.1	

*Snow and rain.
†Total precipitation for 12 months. July 1938 through June 1939 was 42.24 inches.

TABLE 3.—*Sheep gains or losses and pasture days of grazing on one-third acre areas.**

Plot No.	Treatment†	1938, pasture days	1939	
			Pasture days	Total gain or loss in weight of sheep, lbs.
1	Lime, phosphate; intensively grazed	335	202	+9
2	Lime, phosphate; regulated grazing	166	198	+68
3, 4	No soil treatment; intensively grazed	225	182	−13
5	No soil treatment; regulated grazing	83	112	+21

*A pasture day refers to pasturing of one yearling ewe for one day.
†Plots were treated and seeded in September 1936. The first season of grazing was during 1938.

grazing, while those on the untreated plot where grazing was regulated gained 21 pounds during 112 pasture days. In view of this small gain and only 112 pasture days of grazing, it is very doubtful whether production can be improved to any practical extent in humid areas by controlling grazing without soil treatment, particularly where initial fertility levels are low.

During the first season of grazing, land intensively or severely grazed furnished more pasture days of grazing than land on which grazing was well controlled or regulated. In 1938, 335 days of pasturage were obtained from the treated and intensively grazed ⅓ acre plot, while 166 pasture days were obtained from the treated plot on which grazing was regulated (Table 3). Plot 3 and 4, not treated but intensively grazed, furnished 225 pasture days while plot 5, untreated and on which grazing was regulated, furnished 83 pasture days. A decrease in pasture days of grazing was expected during the first season as the forage on plots to be severely grazed entered the season with root reserves equal to reserves on those which were to be moderately grazed.

SUMMARY

This paper presents the results of an experiment conducted at the Dixon Springs Experiment Station as a cooperative project between the Illinois Agricultural Experiment Station and the Soil Conservation Service, Research Division. The purpose of the experiment is to determine the effect of intense and moderate grazing and soil treatment on soil and water losses and forage values of pastures.

Four areas ⅓ acre in size were fenced and grazed with sheep. Small run-off plots 70 by 14 feet in size were located within the grazing areas and it was from these small plots that soil and water losses were measured. Intense and regulated grazing was practiced on both treated and untreated soil.

Forage yields and vegetal data were obtained by random sampling of small areas by the point quadrat method. Days of pasturage with yearling ewes are reported for 1938 and 1939. In 1939, pounds of gain or loss in weight of sheep are also given.

The amount of vegetative cover on treated land on which regulated grazing was practiced was from three to four times greater than

on land intensively grazed. Regulation of grazing did not markedly increase the amount of cover on untreated land. Severe grazing and lack of soil treatment increased the proportion of undesirable vegetation.

Soil losses from land with established vegetal cover, even under conditions of severe grazing management and low fertility, were very small. Annual weedy grasses which were abundant on untreated land under intensive grazing protected the soil against erosion.

Run-off losses from intensively grazed land that was treated with limestone and phosphorus were greater than from land similarly treated that was moderately grazed. On the untreated plots, grazing management did not significantly affect the run-off losses.

Under moderate grazing run-off losses from land untreated were greater than from land which was treated, but the losses were not greater under severe grazing. These results were influenced by the type of weed growth which is produced on untreated land.

Number of pasture days of grazing with sheep were approximately the same on treated land under the two intensities of grazing. On land not treated, fewer days of grazing were obtained under moderate than severe grazing management.

Yearling ewes gained considerably more during the grazing season on treated land when grazing was regulated than when grazing was severe.

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THE EFFECT OF SOIL CHARACTERISTICS AND WINTER LEGUMES ON THE LEACHING OF POTASSIUM BELOW THE 8-INCH DEPTH IN SOME ALABAMA SOILS[1]

N. J. VOLK[2]

A SOLUBLE salt added to the soil will leach into the subsoil as the drainage water moves downward unless something obstructs its passage. In the case of a soluble potassium salt, absorption by plants, soil flora, and exchange material will retard or inhibit the downward passage of the potassium. Truog and Jones[3] reviewed the literature and found that losses of potassium due to leaching varied between practically none and 70 pounds per acre annually, with an average of 10 to 15 pounds per acre per year.

It is the purpose of this paper to report the extent to which potassium has leached below a depth of 8 inches in 8 years when it was applied in varying amounts to different soils and under different cropping systems on fertility plots located on Alabama substations and experiment fields.

METHOD OF INVESTIGATION

Assuming that the greater portion of the potassium that leached below the 8-inch depth would be caught by the exchange material in the 8- to 24-inch depth, a study was made of the distribution of potassium in the soil profile to a depth of 24 inches before and after 8 years of cropping and fertilizing.

A total of 210 plots on eight different soil types were sampled at the 0- to 8-, 8- to 16-, and 16- to 24-inch depths in most cases. Each plot consisted of about 1/40 acre. In sampling a plot, soil was taken from 12 locations to form a composite sample. These samples were then analyzed for soluble and replaceable potash by leaching with ammonium acetate and precipitating the potassium as potassium sodium cobaltinitrite.

EFFECT OF SOIL TEXTURE AND AMOUNT OF POTASSIUM APPLIED PER ACRE ON AMOUNT OF POTASSIUM LEACHED BELOW THE 8-INCH DEPTH

The rates of potash tiers were sampled for this study. These tiers are located on three types of soil as follows: (1) Norfolk fine sandy loam having a friable sandy clay loam subsoil, (2) Hartsells very fine sandy loam having a friable sandy clay loam subsoil, and (3) Decatur clay having a compact but friable clay subsoil. These tiers were cropped continuously to cotton without summer or winter legumes. The amounts and kinds of fertilizer applied annually to the plots were 36 pounds of nitrogen as sodium nitrate, 60 pounds of P_2O_5 as superphosphate, and 0 to 80 pounds of potassium as the muriate.

From the results of the analyses given in Table 1 it is apparent that the nature of the soil has a definite influence on the amount of

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[2]Soil Chemist.

[3]TRUOG, E., and JONES, R. J. Ind. and Eng. Chem., 30:882–885. 1938.

potassium that is leached below the 8-inch depth. In the case of Norfolk fine sandy loam, about as much potassium leached into the 16- to 24-inch layer as leached into the 8- to 16-inch layer, a condition which indicates that a large amount of potassium may have passed below the 24-inch depth. On the other hand, most of the leached potassium was held in the 8- to 16-inch depth of the Hartsells very fine sandy loam, and practically none was leached below the 8-inch depth in the case of Decatur clay.

TABLE 1.—*The amounts of potassium leached below a depth of 8 inches in 8 years when various amounts of muriate of potash were applied to soils of different texture.*

Texture of the soil		Pounds of potassium applied per acre*		Pounds of potassium per acre that leached into and were retained by		Amount of potassium per acre that leached into and was retained by the 8 to 24 in. depth	
Surface	Subsoil	Annual application	Total applied in 8 years	The 8–16 in. depth	The 16–24 in. depth	Pounds per acre	Per cent of total potassium applied
			Norfolk				
Fine sandy loam	Sandy clay loam	10	80	5	2	7	9
		20	160	23	17	40	25
		40	320	49	43	92	29
		80	640	114	102	216	34
			Hartsells				
Very fine sandy loam	Sandy clay loam	10	80	7	2	9	11
		20	160	19	11	30	19
		40	320	38	26	64	20
		80	640	158	42	200	31
			Decatur				
Clay	Clay	10	80	0	0	0	0
		20	160	3	6	9	6
		40	320	12	11	23	7
		80	640	31	25	56	9

*Duplicate plots were installed for each treatment.

The amount of potassium that leached below the 8-inch depth was directly proportional to the amount of potassium applied.

Since the loss of potash through leaching is a factor of considerable importance as shown by these data, systems of cropping should be employed which will minimize this loss.

USE OF WINTER LEGUMES FOR PREVENTING LEACHING OF POTASSIUM

In another set of tiers of plots scattered over eight different soil types in the state, a winter legume was used in the rotation on some of the plots. This condition offered a chance to study the effect of winter legumes in conserving applied potassium. A total of 128 plots

which had received an average of 24 pounds of potassium annually or a total of 192 pounds in 8 years, were sampled at the 8- to 24-inch depth and analyses were made for replaceable and soluble potassium.

The data in Table 2 show that winter legumes were very effective in preventing leaching of potassium below the 8-inch depth. The percentage of applied potassium lost was reduced from 20.2% to 3.1%.

TABLE 2.—*The amounts of potassium leached into the subsoil when winter legumes were or were not present in the rotation.*

Soil*			Percentage of applied potassium that leached into the 8–24 in. layer of the subsoil in 8 years		Percentage of potassium applied that was prevented from leaching by being absorbed by the legumes
Series	Texture of surface	Texture of subsoil	No winter legumes in the rotation	Winter legumes in the rotation	
Kalmia	Very fine sandy loam	Clay	8.9	2.7	6.2
Greenville	Clay	Clay	12.2	2.7	9.5
Hartsells	Very fine sandy loam	Sandy clay loam	18.1	0	18.1
Decatur	Clay	Clay	19.9	3.8	16.1
Orangeburg	Fine sandy loam	Clay	21.1	6.4	14.7
Decatur (eroded)	Clay	Clay	23.0	3.4	19.6
Norfolk	Sandy loam	Sandy loam	26.1†	4.2	21.9
Norfolk	Fine sandy loam	Sandy clay loam	32.1	1.9	30.2
Average			20.2	3.1	17.1

*The number of fertility plots investigated ranged between 12 and 38 for each soil type.
†Analyses of the 8- to 16- and the 18- to 24-inch depths indicated that a large amount of potassium leached even below the 24-inch depth in this soil due to the very sandy nature of the subsoil.

DISCUSSION AND SUMMARY

From the results of this investigation, it is apparent that the leaching of potassium below the 8-inch depth is a factor of major importance in certain of the more sandy soils of Alabama. The texture of the soil and the type of plants grown will, of course, cause great differences in the amount of potassium that is leached downward. The data show that when no winter legumes were grown, the amount of potassium leached into the 8- to 24-inch layer and retained there over an 8-year period amounted to from 9 to 32% of the amount added. On the other hand, when winter legumes were grown, the amount of potassium leached was from 0 to 6% of the amount added. The potassium saved through winter legumes amounted to about 17% of the total potassium applied.

Winter legumes, therefore, in addition to aiding in the prevention of soil erosion and to supplying nitrogen to the succeeding crops, are important from the standpoint of conserving soil potassium.

VIABILITY OF BUFFALO GRASS SEEDS FOUND IN THE WALLS OF A SOD HOUSE[1]

ALVIN E. LOWE[2]

A NUMBER of well-preserved burs of buffalo grass (*Buchloë dactyloides* Nutt.) were found during November, 1939, in the broken portions of the walls of a sod house located in Greeley County, Kansas. The walls were built of sod blocks laid up in the manner of bricks, except no mortar was used. The sod blocks were about 18 inches square and 4 inches thick. The grassy side of the sod was turned down so it could be shaved to a uniform thickness with a spade and a neater and more nearly plumb wall made. The inside walls were plastered with lime and the nearly flat roof was of wooden planks covered with tar paper. The walls were unprotected on the outside and no foundation of any sort had been used.

The grass in these walls was well preserved except for a few inches at the outside edges of the sods, evidently where rainwater had penetrated and discolored it. In the center of the walls the grass was bright in color and formed a thick mat, as shown in Fig. 1. Some of

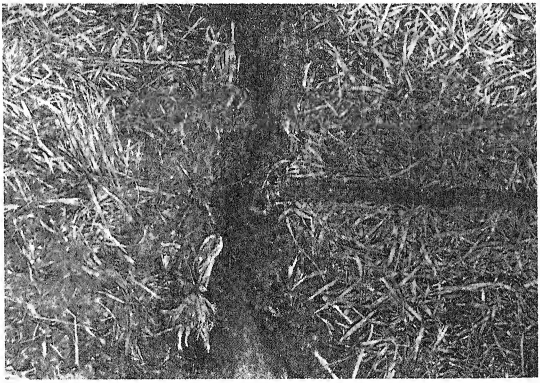

FIG. 1.—Small buffalo grass sod at left is from walls of rooms built 35 years ago. The large sod at the right is from wall of room built 25 years ago. Note bur lying as found near the two on the 6-inch rule. ×⅝.

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[2]Assistant Agronomist, Garden City Branch of the Kansas Agricultural Experiment Station and Cooperative Agent, Division of Research, Soil Conservation Service.

the leaves and stolens of the 25-year-old sod still had a light green color. The sods were full of strong roots which held them together. The sod was nearly all buffalo grass with a small quantity of blue grama (*Bouteloua gracilis* H. C. K.) and a few small unidentified herbaceous plants.

The buffalo grass burs were nearly all found under the grass leaves and in shallow depressions which were probably hoof marks of animals that had grazed on the grass. The burs appeared so well preserved (Fig. 2) that it was decided to see if any of the caryopses were viable. Lacking proper facilities at this station for testing germination, 18 burs from the outside walls of the room constructed in 1915 were given to Mr. D. A. Savage, Agronomist, Division of Forage Crops and Diseases, Southern Great Plains Field Station, Woodward, Oklahoma. From these 18 burs, 20 caryopses were obtained and planted in individual paper pots at a depth of ½ inch in sterilized soil. They were watered with distilled water and kept in a greenhouse. From these 20 caryopses which were 25 years old, 3 seedling plants of buffalo grass were obtained. These data are presented in Table 1.

TABLE 1.—*The age, number and percentage of viable buffalo grass caryopses found in the walls of a sod house.*

Germination test method	Age in years	Number			Percentage viable
		Burs	Caryopses	Viable	
Soil in greenhouse at Woodward, Okla.	25	18	20	3	15
Seed germinator at Manhattan (1st test)	25	19	14	11	78
Seed germinator at Manhattan (2nd test)	25	32	40	7	18
Total		69	74	21	28
Seed germinator at Manhattan	35	93	50	0	0

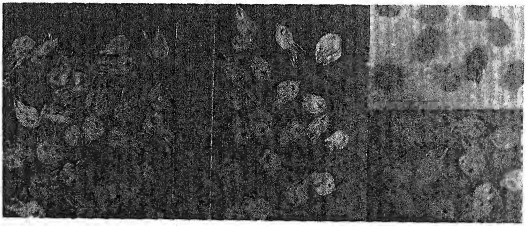

FIG. 2.—Buffalo grass burs at left of rule are from sod 25 years old, those to the right are 1 year old, and those at the extreme right are 35 years old with the dark colored ones placed on a light background. ×1.

Fearing some unforeseen accident might cause a complete loss if all the burs were tested by one method at the same time and place, 19 of them were given to Mr. Kling L. Anderson, Assistant Professor of Pasture Management, Agronomy Department, Kansas State College, Manhattan, Kansas. From these 19 burs 14 caryopses were obtained and these were placed on moist filter papers in Petri dishes and germinated according to regular seed laboratory practices. Eleven of the 14 caryopses germinated and were transplanted to pots in the greenhouse.

Later, another group of 32 burs from walls of the room constructed in 1915 was tested by Mr. Anderson. In these 32 burs there were 40 caryopses of which 7 germinated and were transplanted to pots in the greenhouse.

From the walls of the two rooms built in 1905, 93 burs were obtained. These contained 50 caryopses which were apparently in a fairly good state of preservation. Only a few of these 35-year-old burs looked bright and fresh; many were slightly discolored and a few were dark colored and crumbled under slight pressure. These burs are shown in Fig. 2. None of these 35-year-old caryopses germinated when placed on moist filter papers in Petri dishes and tested under regular seed laboratory procedure.

In this article the author has stated the age of the buffalo grass burs as being the same as that of the walls from which they were removed, but the possibility of a portion or all of them having been produced in years previous to the construction of the walls should not be overlooked.

The 21 buffalo grass plants secured are being grown in greenhouses at Manhattan and Woodward. Those that survive will be set in the field so they can be compared with buffalo grass that has been growing and therefore subjected to environmental selection during this 25-year period.

"MILORGANITE" AS A SOURCE OF MINOR NUTRIENT ELEMENTS FOR PLANTS[1]

C. J. REHLING AND EMIL TRUOG[2]

DRIED activated sludge is produced at the rate of over 100 tons daily at the Milwaukee Sewage Disposal Plant and sold under the trade name of "Milorganite". Results have been obtained from the use of this fertilizer which indicate appreciable benefits from constituents other than the nitrogen and available phosphoric acid contents of 6 and 2.5 per cent respectively. These results have been noted especially on very sandy soils, particularly in the Southeast where striking benefits from the use of boron, copper, manganese, and zinc have been reported. It was therefore believed that these minor nutrient elements might account, at least in part, for some of the favorable effects produced by Milorganite.

An extended analytical study of Milorganite (31)[3] revealed the presence of some twenty-three elements, a number of which can serve as plant nutrients. Significant amounts of boron, copper, manganese, and zinc were found to be present in an available form as determined by extraction with a solution of carbonic acid. The importance of these elements in plant nutrition is now generally recognized (38). The experiments described in this paper were carried out to determine if Milorganite could supply the minor nutrient elements required by plants.

NEED OF MINOR NUTRIENT ELEMENTS

Boron.—That boron is essential was demonstrated by McHargue and Calfee (24) for lettuce; by Ferguson (13) for cauliflower; by Askew and Chittenden (4) for apples; by van Schreven (37) for tomatoes; by Purvis and Ruprecht (30) for celery; by McMurtrey (26) for tobacco; and by Foex and Burgevin (14) for sugar beets. The occurrence of boron deficiency in the soils of the Coastal Plain and other areas has been reported by Willis and Piland (39), Naftel (29), McHargue and Calfee (25), and others.

The symptoms of boron deficiency usually reported are distorted leaves, depressed growth, and death of terminal buds. A breakdown of meristematic tissue and serious interference with translocation probably accounts for the observed increase in starch and sugar contents of leaves of plants which are not supplied with boron.

Copper.—Increased productivity of peat and muck soils from the addition of copper has been reported by Allison, *et al.* (1), Felix (12), Harmer (18), and others.

[1]Contribution from the Department of Soils, University of Wisconsin, Madison, Wis. and published with the permission of the Director of the Wisconsin Agricultural Experiment Station. This paper represents, in part, thesis material submitted by the senior author to the faculty of the University of Wisconsin in partial fulfillment of the requirements for the degree of doctor of philosophy. The work here presented was supported in part by a fellowship grant from the Milwaukee Sewerage Commission, Milwaukee, Wis. Received for publication September 23, 1940.

[2]Formerly, Fellow, University of Wisconsin; now Senior State Toxicologist, Auburn, Ala.; and Professor of Soils, University of Wisconsin, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 905.

More recently, however, benefits have been reported from the use of copper on mineral soils by Andersen (2), Churchman, *et al.* (9), Hill and Bryan (19), and others.

Copper seems to be necessary in very small amounts for normal growth, chlorophyll formation, and seed production in plants, as was demonstrated by Sommer (35) and Lipman and Mackinney (21). Chlorotic spotting of leaves, curling or "frenching", and death of young shoots or branches are some of the symptoms usually associated with a deficient supply of copper, particularly in fruit and citrus trees. Stunted growth is the commonly reported symptom in the grasses and most crop plants.

Manganese.—McHargue (22), Haas (17), and others have shown that many crop plants fail to grow normally if manganese is excluded from the nutrient supply. That manganese is frequently lacking in soils was reported by Gilbert (16), Conner (11), Miller (27), Schreiner and Dawson (32), McHargue and Shedd (23), and many others. Gaddum and Rogers (15) report the presence of small amounts of manganese in a number of the common fertilizer materials.

Molybdenum.—It is only recently that attention has been directed to the presence and importance of molybdenum in plants, and very little information is available. Ter Meulen and Ravensway (36) found molybdenum in many kinds of leaves which they examined. Arnon (3) reported additional growth of plants after adding molybdenum, together with several other elements, to an otherwise complete culture solution. Hoagland and Arnon (20) obtained definite chlorotic symptoms in tomatoes by growing the plants in cultures lacking in molybdenum.

Zinc.—That zinc is essential for higher plants was emphasized by the solution culture work of Sommer (34). The use of zinc as a specific corrective for certain abnormalities has been reported by Mowry and Camp (28) for tung trees; by Barnette and Warner (5) for corn; by Chandler, *et al.* (7) for fruit trees; by Chapman, *et al.* (8) for citrus; and by Cole, *et al.* (10) for pecan trees.

The symptoms associated with a deficiency of zinc are chlorosis and stunted growth which in severe cases are followed by death of the affected parts or even of the entire plant. Frenching and rosetting of growing tips are frequently observed symptoms in fruit and citrus trees.

CORN EXPERIMENT

From earlier studies (31) it was found that Milorganite contained 0.0115% B_2O_3, 0.0431% CuO, 0.0250% MnO, and 0.030% ZnO. The following amounts were found to be readily available as determined by extraction with carbonated water: 0.0035% CuO, 0.0062% MnO, and 0.026% ZnO. Water-soluble boron was found to be present to the extent of 0.0073% B_2O_3. In order to check further the ability of Milorganite to furnish minor nutrient elements to plants, solution cultures were set up to some of which a carbonic acid extract of Milorganite was added as the only source of these minor elements.

PLAN OF SOLUTION CULTURES

Duplicate series of cultures were prepared. Each series included a control culture with complete nutrient medium and cultures from which were omitted either copper, manganese, or zinc, both singly or in combination. Boron was supplied to all cultures in this experiment.

The following salts were added in amounts indicated as basal nutrients to each culture:

KH_2PO_4 .... 0.362 gram per liter
$Ca(NO_3)_2.4H_2O$ .... 0.486 gram per liter
$MgSO_4.7H_2O$ .... 0.250 gram per liter
NaI .... 0.00025 gram per liter

Where the minor nutrient elements were added, the following amounts were supplied whether singly or in combination:

H_3BO_3 .... 0.0028 gram per liter, equivalent to 0.50 p.p.m. boron
$CuSO_4.5H_2O$ .... 0.0002 gram per liter, equivalent to 0.05 p.p.m. copper
$MnSO_4.4H_2O$ .... 0.0021 gram per liter, equivalent to 0.50 p.p.m. manganese
$Zn(C_2H_3O_2)_2.2H_2O$ .. 0.0017 gram per liter, equivalent to 0.05 p.p.m. zinc

The concentration of copper was later lowered to 0.02 p.p.m. since 0.05 p.p.m. appeared to be slightly toxic as indicated by comparison with plants of the control cultures. Iron was supplied when needed as ferrous sulfate which was prepared from pure iron wire. All salts used in this and the following experiments were of analytical reagent grade and were not further purified or tested for the minor nutrient elements; however, the physiological tests made later indicated a high degree of purity in this respect.

For containers, quart Mason jars were darkened with heavy paper and provided with paraffined corks. To minimize contamination by dust, the cultures were housed in a cellophane enclosure built upon a greenhouse bench. A double thickness of gauze toweling replaced a portion of the cellophane on one side of the enclosure to provide ventilation and access to the plants.

Two seedlings of yellow corn were transferred to each culture on February 2, 1939. Beginning with once a week, the nutrient solutions were thereafter renewed with increasing frequency as the plants grew, so that during the last week or more just prior to harvesting, renewals were made every other day.

On March 8, and with each solution renewal thereafter, 100-cc portions of a carbonic acid extract of Milorganite were added to each jar of one series of treatments including a control. This extract was prepared as needed by shaking 10 grams of Milorganite with 1 liter of carbonated water (pH 4.5) for 24 hours and filtering. Each 100 cc of this extract represented, as determined by analyses (31), an addition of 0.028 mgm of copper, 0.048 mgm of manganese, and 0.21 mgm of zinc. Beneficial effects from this extract were evident after about 5 days, and the marked improvement in appearance and growth of the plants continued until they were harvested.

The plants, both tops and roots, were harvested on March 25. Copper and manganese were determined in the dried plants by the colorimetric xanthate and periodate methods, respectively, while zinc was determined by the nephelometric ferrocyanide method (33).

RESULTS

Very characteristic deficiency symptoms developed where zinc was omitted from the cultures. Stiff, straight, and narrow leaves resulted which tended to fold together upwards along the middle rib. Their color was of a gray-green shade and translucent areas appeared at the leaf ends. The younger, emerging leaves were increasingly affected with chlorosis, and large, white areas were evident where chlorophyll was practically absent.

The lack of manganese caused a weak and characteristically chlorotic condition which lacked rigidity. Similar symptoms developed where copper and zinc were omitted from the nutrient solution.

About March 13 certain abnormalities became noticeable in the plants growing without added copper. Chlorotic stripes appeared in the younger leaves and the upper internodes remained very short. This condition became progressively more pronounced, while one plant grew an abnormal tip from this stunted region. These symptoms never appeared in the duplicate culture which received Milorganite extract.

Table 1 gives the dry weights and minor element content of the corn plants. In general, the amounts of copper, manganese, and zinc in the plants are closely correlated with the amounts of growth expressed by the dry weights. In every instance where a minor element deficiency existed and Milorganite extract was later added, increased yields resulted which are attributed to correction of the deficiency by the minor elements contained in the extract.

SUNFLOWER EXPERIMENT

The favorable results of the first experiment prompted a second experiment with solution cultures of sunflower under more carefully controlled conditions. Molybdenum was included among the minor nutrient elements studied.

PLAN OF SOLUTION CULTURES

Two series of cultures were included as in the experiment with corn. Treatments in each series included controls receiving all nutrient elements and cultures deficient in all or one of the minor elements boron, copper, manganese, molybdenum, and zinc. A carbonic acid extract of Milorganite was added to one series after the first week.

Instead of Mason jars, liter Pyrex beakers were used for containers as recommended by other workers (34). Where boron was the particular element under consideration, half-gallon Mason jars were cut to approximate the beakers in capacity and were substituted for the Pyrex beakers. Covers were molded from plaster of paris and paraffined for the protection of solutions and plants. The water used was distilled from glass containers.

Basal nutrients, similar as regards kinds and amounts used in the first experiment, were again added.

Minor nutrient element additions were the same as in the corn experiment with the following changes and additions:

$CuSO_4 \cdot 5H_2O$ changed to 0.0001 gram per liter, equivalent to 0.02 p.p.m. copper

$H_2MoO_4 \cdot H_2O$ added at the rate of 0.00005 gram per liter, equivalent to 0.02 p.p.m. molybdenum

Sunflower seeds were germinated in acid-washed sand and two seedlings were transferred to each culture on March 23.

On March 29, when the solutions were renewed, a 100-cc portion of Milorganite extract, prepared as already described, was added to each culture of one series. This addition was repeated with each subsequent renewal of the solutions until the plants were harvested on April 21.

TABLE 1.—*Growth and minor element content of corn plants as influenced by adding minor elements and Milorganite extract to basal culture solution, the Milorganite extract being added only during last third of growth period.*

Addition to basal culture solution*	Dry weight of tops and roots (2 plants), grams	Content of two plants					
		Copper		Manganese		Zinc	
		Mgms	P.p.m.	Mgms	P.p.m.	Mgms	P.p.m.
1. Minor elements	28.87	0.980	34	11.3	400	3.26	113
2. Minor elements + Milorganite extract	26.37	1.530	58	13.0	490	3.30	125
3. Boron	0.32	0.013	41	0.0	0	0.03	94
4. Boron and Milorganite extract	1.39	0.040	29	Trace	0	0.29	206
5. Minor elements lacking copper	29.87	0.41	14	14.6	490	4.20	140
6. Minor elements lacking copper + Milorganite extract	33.20	1.19	36	11.0	330	5.80	175
7. Minor elements lacking manganese	0.85	0.09	106	0.0	0	0.31	364
8. Minor elements lacking manganese + Milorganite extract	2.67	0.17	64	0.0	0	0.37	140
9. Minor elements lacking zinc	3.82	0.25	66	3.8	1,000	0.09	24
10. Minor elements lacking zinc + Milorganite extract	5.21	0.43	84	4.6	880	0.81	155

*Basal culture solution contained all of the major nutrients, and minor elements consisted of boron, copper, manganese, and zinc.

Analyses of the total dry tissue (tops and roots) in each case were made for copper, manganese, and zinc by the methods used in the first experiment. Boron was determined in all samples by the colorimetric quinalizarine method (33). No attempt was made to determine molybdenum due to lack of sufficient plant tissue.

RESULTS

Significant differences in appearance of the plants were evident after about 2 weeks growth. Excepting the control, the plants receiving Milorganite extract were much superior in size and appearance to their respective duplicates in other series which were not receiving the extract. These differences became increasingly prominent up to the time of harvest. The lack of manganese gave rise to a characteristic, patterned chlorosis of the leaves and to severely retarded growth. The lack of boron caused the most noticeable effect, the plants having never produced true leaves and being dead at harvest. Retarded growth, together with sudden yellowing and death of the leaves, was associated with a deficient supply of zinc. The lack of molybdenum merely retarded growth without any noticeable chlorosis, and similar results were observed in the case of copper deficiency.

The effect of adding Milorganite extract was striking in all cultures otherwise deficient in one or more of the minor nutrient elements. Although the amounts of growth were not identical throughout the series receiving the extract, large increases due to this addition were apparent and are illustrated in Figs. 1 and 2. Growth differences associated with the addition of the extract to the control cultures receiving a complete nutrient solution were negligible.

Further expression is given to these observations through the dry weights and minor element contents of the plants given in Table 2. The correlation between yield and content of each of the minor elements is generally quite close. Milorganite extract increased the total amount of each of these elements in the plants. A deficient supply of molybdenum definitely lowered the yield of dry tissue.

TOMATO EXPERIMENT

Since tomato plants are known to require considerable amounts of the minor nutrient elements for normal growth, a further experiment was conducted with this plant.

PLAN OF CULTURES

This experiment with tomatoes was planned and executed in all respects as was the experiment with sunflowers, including the specific treatments.

The tomato plants (Earliana) were transferred to the culture solutions as seedlings on March 22, and the addition of Milorganite extract to one series was started at the time of renewing the solutions on March 29. Due to the slower growth of tomatoes, these cultures were continued for a longer period than the sunflowers and were harvested on April 29.

Analyses for boron, copper, manganese, and zinc were made by the same procedures as for the sunflower.

TABLE 2.—*Growth and minor element content of sunflower plants as influenced by adding minor elements and Milorganite extract to basal culture solution, Milorganite extract being added during last 3 weeks of 4-week growth period.*

Addition to basal culture solution*	Dry weight of tops and roots (2 plants), grams	Content of two plants							
		Boron		Copper		Manganese		Zinc	
		Mgms	P.p.m.	Mgms	P.p.m.	Mgms	P.p.m.	Mgms	P.p.m.
1. Minor elements	5.65	0.40	71	0.23	41	0.52	92	0.57	100
2. Minor elements + Milorganite extract	6.77	0.50	74	0.56	83	0.60	89	0.78	108
3. No addition	0.40	0.05	120	0.02	60	0.00	0	0.00	0
4. Milorganite extract	2.15	0.11	51	0.22	102	0.08	35	0.15	71
5. Minor elements lacking copper	3.63	0.30	84	0.02	6	0.25	68	0.37	102
6. Minor elements lacking copper + Milorganite extract	6.52	0.52	78	0.19	30	0.42	64	0.60	92
7. Minor elements lacking manganese	0.77	0.11	140	0.06	73	0.00	0	0.14	180
8. Minor elements lacking manganese + Milorganite extract	4.39	0.40	91	0.31	70	0.18	41	0.50	113
9. Minor elements lacking zinc	2.15	0.19	89	0.10	47	0.30	140	0.02	9
10. Minor elements lacking zinc + Milorganite extract	5.37	0.43	80	0.29	53	0.53	98	0.46	85
11. Minor elements lacking boron	0.25	0.01	40	0.06	260	0.01	44	0.04	145
12. Minor elements lacking boron + Milorganite extract	3.21	0.19	59	0.29	93	0.37	115	0.40	126
13. Minor elements lacking molybdenum	3.98	0.25	63	0.35	89	0.20	50	0.40	100
14. Minor elements lacking molybdenum + Milorganite extract	5.22	0.36	68	0.37	71	0.42	80	0.62	118

*Basal culture solution contained all of the major nutrients, and minor elements consisted of boron, copper, manganese, molybdenum, and zinc.

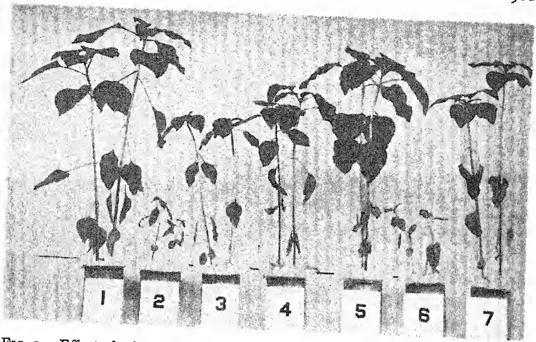

FIG. 1.—Effect of minor nutrient elements and Milorganite extract on the growth of sunflowers in culture solutions. Milorganite extract added only during last 3 weeks of the 4-week growth period. 1, control, all basal and minor nutrients supplied; 2, basal nutrients only; 3, basal nutrients+Milorganite extract; 4, basal nutrients+minor elements lacking copper; 5, basal nutrients+minor elements lacking copper+Milorganite extract; 6, basal nutrients+minor elements lacking manganese; and 7, basal nutrients+minor elements lacking manganese+Milorganite extract.

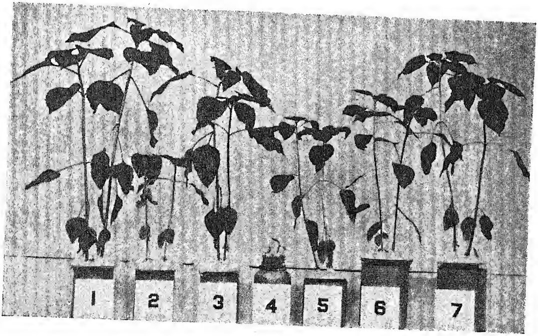

FIG. 2.—Effect of minor nutrient elements and Milorganite extract on the growth of sunflowers in culture solutions. Milorganite extract added only during last 3 weeks of the 4-week growth period. 1, control, all basal and minor nutrients supplied; 2, basal nutrients+minor elements lacking zinc; 3, basal nutrients+minor elements lacking zinc+Milorganite extract; 4, basal nutrients+minor elements lacking boron; 5, basal nutrients+minor elements lacking boron+Milorganite extract; 6, basal nutrients+minor elements lacking molybdenum; and 7, basal nutrients+minor elements lacking molybdenum+Milorganite extract.

RESULTS

Much of what was stated in describing the deficiency symptoms and growth of the sunflowers appropriately describes the results obtained with tomatoes. At harvest, many of the leaves of the manganese- and zinc-deficient plants were dying rapidly from the tips and edges. The symptoms of copper and molybdenum deficiencies were similar to but not as acute as those described by Hoagland and Arnon (20). Molybdenum deficiency appeared as a mild but general chlorosis which developed into a spotted pattern as the leaves approached full size. A leaf so affected bore some resemblance to one showing a mild manganese deficiency. Distorted growing tips and stunted growth characterized the plants which were deficient in boron.

At no time did the tomato plants which received Milorganite extract exhibit symptoms of minor element deficiencies. They appeared quite normal, although the amount of growth was generally not the equal of that made by controls, due probably to the addition of insufficient extract.

The yields and results of analyses of the tomato plants are given in Table 3. As with corn and sunflowers, the yields are closely related to the amounts of minor nutrient elements contained in the plants. The boron contents of Nos. 3 and 7, expressed as p.p.m., are irregularly high. Similarly, the manganese content of No. 9 and the zinc content of No. 11 are out of line, but these irregularities occurred in cases of severely retarded growth. Increases in the minor element contents and yields are associated with the addition of Milorganite extract to the cultures, other than the controls.

DISCUSSION

If ordinary precautions are observed, culture solutions may be quite readily prepared which are sufficiently free of the elements boron, copper, manganese, and zinc, respectively, so that little plant growth will occur.

A deficiency of boron permits of practically no growth in sunflower and tomato and finally specific disorders develop in the meristematic tissues which result in death of the plant. Chlorosis and the lack of structural rigidity, as observed in corn, sunflower, and tomato, indicates that a deficiency of manganese causes acute disturbance of general plant metabolism. Though required in smaller amounts than manganese, zinc seems to play an equally important role in plant life, since a deficient supply permits of little growth and causes a chlorosis which is followed by death of the leaves or of the entire plant. The symptoms of zinc deficiency in sunflowers agree closely with those described by Sommer (34).

Due in part to the very small amounts of copper required by plants for normal growth and in part to the difficulty of eliminating the last traces of this element from the nutrient medium, the development of severe deficiency symptoms was not as striking as with the other elements. Traces of copper were evidently contained in the nutrient salts used, since the tissue analyses revealed the presence of small amounts in all of the plants which were grown without

TABLE 3.—*Growth and minor element content of tomato plants as influenced by adding minor elements and Milorganite extract to basal culture solution, Milorganite extract being added during last 4 weeks of 5-week growth period.*

Addition to basal culture solution*	Dry weight of tops and roots (2 plants), grams	Content of two plants							
		Boron		Copper		Manganese		Zinc	
		Mgms	P.p.m.	Mgms	P.p.m.	Mgms	P.p.m.	Mgms	P.p.m.
1. Minor elements	9.25	0.56	60	0.26	28	1.45	156	1.00	108
2. Minor elements + Milorganite extract	8.77	0.60	69	0.34	39	1.98	230	1.23	141
3. No addition	0.20	0.07	350	0.04	200	0.00	0	0.00	0
4. Milorganite extract	5.65	0.16	28	0.18	32	0.45	80	0.46	82
5. Minor elements lacking copper	2.83	0.18	63	0.06	21	0.36	127	0.28	100
6. Minor elements lacking copper + Milorganite extract	5.25	0.19	36	0.21	40	0.87	165	0.62	118
7. Minor elements lacking manganese	0.52	0.09	170	0.05	96	0.00	0	0.74	142
8. Minor elements lacking manganese + Milorganite extract	4.27†	0.27	63	0.14	33	0.33	90	0.55	130
9. Minor elements lacking zinc	0.88	0.08	91	0.05	57	0.31	350	0.01	11
10. Minor elements lacking zinc + Milorganite extract	2.74	0.18	64	0.12	44	0.41	150	0.21	77
11. Minor elements lacking boron	0.23	Trace	—	0.07	31	0.40	174	0.05	208
12. Minor elements lacking boron + Milorganite extract	2.39	0.12	50	0.09	37	0.39	162	0.73	153
13. Minor elements lacking molybdenum	4.59	0.26	55	0.13	28	0.41	88	0.41	89
14. Minor elements lacking molybdenum + Milorganite extract	3.82	0.26	68	0.18	47	0.34	90	0.52	137

*Basal culture solution contained all of the major nutrients, and minor elements consisted of boron, copper, manganese, molybdenum, and zinc.
†One plant only.

intentional additions of this element. These amounts, however, were insufficient for maximum growth, and the results agree with those of numerous workers which indicate that copper is essential for plant growth.

Molybdenum seems to play an important role in plant growth as is evidenced by the reduced dry weight of sunflower and the chlorotic disorder noted in tomatoes when it was not added. The latter result agrees with the symptoms of molybdenum deficiency in tomatoes reported by Hoagland and Arnon (20).

The dry weights of the plants in each experiment are rather well correlated with the amounts of each of the minor nutrient elements found in the plants. Certain anomalies, which occurred in those instances of very low yields, are perhaps due in part to analytical errors such as may result when the amounts of tissue available for analysis are limited. The contents of B, Cu, Mn, and Zn found in the tomato and sunflower tissue indicate that a deficient supply of any one of these nutrient elements will result in the accumulation of a higher content of the others in the plant. A similar conclusion may be reached from the results with corn. The results obtained with molybdenum in the tomato and sunflower experiments show that Milorganite contains traces of this element in available form.

The results in general demonstrate that Milorganite can serve as a satisfactory source of the several minor nutrient elements for plant growth. The recovery made by corn after the addition of Milorganite extract from each of the several deficiencies would undoubtedly have been more striking if the experiment could have been continued for a longer period. Where Milorganite extract served as the only source of one or more of the minor nutrient elements for tomatoes and sunflowers, the growth approached but did not attain that of the controls. This is no doubt due largely to the interval of 1 week that elapsed after starting the cultures before Milorganite extract was supplied, during which time the cultures were, of course, lacking in the minor nutrient elements. Since Milorganite extract did not stimulate additional growth in control cultures which already contained all of the minor nutrient elements, it is evident that the highly stimulating effects of the extract, which were observed in the other cultures, can be attributed only to the presence of available minor nutrient elements in Milorganite.

These observations and results undoubtedly explain, at least in part, the additional unusual stimulating effects which have been noted following the use of Milorganite on certain soils.

SUMMARY

The availabilities of the minor nutrient elements in "Milorganite" and their influence on plant growth were studied by growing corn, tomatoes, and sunflowers in nutrient solutions, some of which were supplied with carbonated water extract of Milorganite as the only source of boron, copper, manganese, molybdenum, and zinc. The tomato and sunflower plants were analyzed for each of these elements, except molybdenum, and corn for each except boron and molybdenum. The results obtained may be summarized as follows:

Corn made very little growth and exhibited typical deficiency symptoms in solution cultures from which either manganese or zinc was omitted, while a fairly large but abnormal growth resulted where copper was omitted. The addition of Milorganite extract to some of these cultures during the last 2 weeks of the 7-week growth period resulted in the resumption of normal growth in each instance. Milorganite extract increased the yield in all cases except in controls which were already supplied with all nutrients. Increases in the amounts of copper, manganese, and zinc absorbed by the plants were noticed wherever the extract was supplied.

Tomato and sunflower plants made good growth in every culture where Milorganite extract served as the only source of one or more of the minor elements. Inferior growth, exhibiting deficiency symptoms, was generally observed in the series of duplicate cultures which did not receive the extract or other sources of these elements. In all cultures that received it, except controls, Milorganite extract significantly increased the dry weights of the plants and the contents of boron, copper, manganese, and zinc.

The results of the investigation show clearly that Milorganite when used as a fertilizer or as a constituent of mixed fertilizer may serve as a source of the minor nutrient elements for plant growth.

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NOTE

A CONTAINER FOR GROWING PLANTS FOR ROOT STUDIES

THE container described here and illustrated in Fig. 1 was designed to obtain data on the relative depth to which certain grasses would root under similar conditions. Since it served this purpose very satisfactorily, a brief description is submitted for the use of others who may be interested in similar studies.

The can was made from 22 gauge galvanized iron unpainted. The upright portion of the container merely rests in the detachable bottom which is pierced to provide drainage. The upright portion is bent into shape and the detachable side is slipped inside the two flanges provided. The pressure of the soil within the container holds the fourth side in place after the can is filled. Metal screws are necessary to keep the container from spreading under the pressure developed by tamping, but need be set no closer than 6 inches. The detachable bottom holds the lower portion of the upright part, so no screws need be set in it.

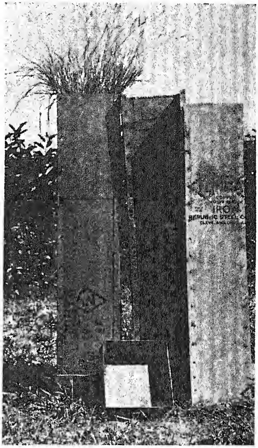

FIG. 1.—General view of the containers.

The cans may be filled, set in the ground, and the crop grown for any designated period.

At the close of the growth period the cans may be dug loose, slipped up a plank, and laid on a plank or floor with the removable side up. The side may then be removed, as illustrated in Fig. 2. These operations expose the soil and the development of the roots may be observed easily, particularly at the bottom of the can, if the roots penetrate so deeply. The soil may then be marked off at definite intervals and various layers sliced off and the roots washed out. The fact that the side may be removed makes it possible to detach these layers quickly and accurately.

The containers illustrated were made 10×10 inches and 4 feet deep. They were small enough to be handled fairly easily and deep enough for this study. There was no indication of buckling, however, and the cans could be made larger if desired.

Each screw should be greased as it is set and a little grease applied to the inside of the detachable bottoms to make sure that they will

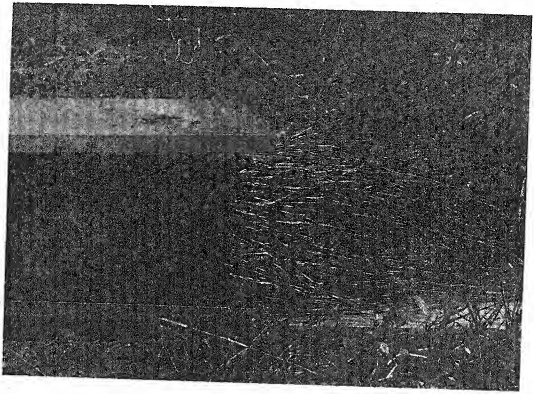

FIG. 2.—Side removed from container with soil exposed.

come apart easily at the close of the growing season. They may be used for several tests.—NEWTON L. PARTRIDGE, *Department of Horticulture, Michigan State College, East Lansing, Mich.*

BOOK REVIEW

GENERAL BACTERIOLOGY

By D. B. Swingle. New York; D. VanNostrand Co., Inc. XII+313 pages, illus. 1940. $3.

THIS book is intended for beginners in bacteriology and it is very elementary. It differs in two respects from many recent text books in this field: The bacteriological aspects of the subject are treated rather less prominently than the more fundamental principles of bacteriology as a science; comparatively little attention is given to yeasts and molds, because of the fact that they are not bacteria and in the author's opinion should be treated separately.

Special interest from the standpoint of agronomy is the fact that 23 pages are given up to the matter of bacteria in soil. This amount of space compares very favorably with the 46 pages given up to pathogenic bacteria. (H. J. C.)

AGRONOMIC AFFAIRS

PROFESSIONAL WORKERS WANT COMPRESSED COURSES

THE May issue of the JOURNAL carried a news note with regard to special short courses for professional workers to be made available at the Agricultural and Mechanical College of Texas during the summer of 1940. The interest which was taken in these courses and the indications that were received as to the value of such courses to the professional workers of the country makes it worthwhile to report the outcome of this summer's trial.

Three outstanding conslusions were reached, as follows: First, professional workers want compressed courses which can frequently be accomplished during short or vacation periods. Second, outstanding visiting instructors can frequently be obtained for such short periods. Third, this type of graduate course permits keeping college instruction geared closely to the latest developments in action programs.

There was a total of 98 students enrolled in these special courses, approximately three-fourths of whom were established professional workers coming back for either a refresher course, a service course, or additional work towards their definite graduate program. These men came from a very wide geographical region and from many professional services. College and experiment station workers, vocational agriculture teachers, soil conservation workers, and employees of the extension service and the U. S. Bureau of Agricultural Economics were represented. The character of students thus assembled created a most helpful atmosphere and made it possible to bring into the class discussions an extremely varied amount of experience and background.

After contacting the instructors who handled these courses, it became rather obvious that even very busy and very prominent men in the educational and administrative fields were occassionally seriously interested in an opportunity to go to some other part of the country and teach some special course which fell within their specialty. Some of them remarked that it was extremely helpful to them to get away from the routine demands of their regular employment, which was frequently administrative, and be able to settle down with a group of stimulating students for three weeks of concentrated effort in collecting, re-organizing, and presenting the subject matter which they have in their minds and in their files but do not have sufficient time to organize under other conditions.

Perhaps of greatest significance was the opportunity such courses presented for bringing into our graduate instruction the very latest information and experience obtained through the operation of the action agencies. The necessity for doing this in connection with those types of agronomic work which these agencies have been developing on a previously unheard of scale has been very clear.

Most agronomists will appreciate the fact that much extremely valuable material is not available for general use because it has not had time to become crystallized in text-book and reference form.

Therefore, it is available to only a very limited number of people who happen to have had personal contact with these later developments.

In all of the special courses offered by the Department of Agronomy of the Agricultural and Mechanical College of Texas this past summer, it was obvious that the bringing together of outstanding authorities and teachers, some of whom were associated with action programs, and a distinguished and varied group of students, many of whom were busily engaged in exploring new fields of agricultural planning and development, gave a good setting for an inter-change of ideas which would bring the very latest and best plans clearly before the group for their consideration and information. It was felt that in view of the very rapid changes and advances being made in all types of agricultural science there was a practically unlimited field for bringing opportunities of this sort before professional workers of the country in order that all might keep as nearly abreast of developments as possible.

The courses offered this past summer included: forest soils, taught by Dr. R. F. Chandler, Jr., Pack Assistant Professor of Forest Soils, Cornell University, with an enrollment of 19 students; range management and ecology, taught by Dr. W. G. McGinnies, Chief, Range Research, U. S. Dept. of Agriculture, Southwestern Forest and Range Experiment Station, Tuscon, Arizona, with an enrollment of 16 students; the fundamentals of grass and pasture improvement, taught by Dr. F. D. Keim, Chairman of the Department of Agronomy, University of Nebraska, Lincoln, Nebraska, with an enrollment of 23 students; and soil classification and mapping, taught by E. A. Norton, Chief, Physical Surveys Division, Soil Conservation Service, Washington, D. C., with an enrollment of 40 students.

Throughout the summer the enrollment and interest increased as people learned more about the courses, and therefore it is hoped that other courses of this character may be made available in Texas in succeeding summers.—IDE P. TROTTER, *Head, Department of Agronomy, Agricultural and Mechanical College of Texas, College Station, Texas.*

MEETING OF CORN BELT SECTION

THE Corn Belt Section of the American Society of Agronomy held its annual field meeting at the Iowa State College at Ames on September 9 and 10. The experimental work in progress at the Agronomy Farm of the Iowa Agricultural Experiment Station was demonstrated and tours arranged to visit the southern Iowa Pasture Improvement Farm at Albia and to examine profiles of some of the major soil types.

The meetings were attended by 300 agronomists from 16 states and were followed on September 11 by a Regional Grassland Conference sponsored by the Society in cooperation with the Association of North Central Experiment Station Directors. Among the main speakers were Dean M. F. Miller, Dean H. P. Rusk, Dr. P. V. Cardon, Dr. O. S. Aamodt, and Extension Director W. H. Brokaw of Nebraska. The attendance was about 250.

USE OF POTASSIC FERTILIZERS IN GREAT BRITAIN

TO ensure that the available supplies of potash be used to the best immediate advantage, regulations have been drawn up by the Ministry of Agriculture in Great Britain, limiting the uses of such fertilizers to the following crops: First, for potatoes and truck garden crops (other than fruit); second for sugar beets and flax; and third for other crops only on those soils markedly deficient in potash.

Where barnyard manure is available or where potash has previously been applied in the rotation, further dressings, even for the above crops, must be omitted or reduced. The manufacturer of compound fertilizers low in potash is suspended. Vendors will be required to obtain an assurance from farmers at the time of sale that the fertilizers will be used in accordance with the directions.

WAR AND AGRICULTURAL ADJUSTMENT

LAST-minute arrangements have been made for a joint conference of the Crops Section of the American Society of Agronomy and of the Soil Science Society on the theme of war and agricultural adjustment, with special reference to grassland agriculture. Dr. O. S. Aamodt, chairman of the pasture committee of the American Society of Agronomy, will act as chairman of the conference.

The following program has been arranged for Friday afternoon, December 6, at the Drake Hotel in Chicago:

1. War and Our Changing Agriculture. Eric Englund, Bureau of Agricultural Economics.
2. Farm Adjustments to Meet Changing Conditions. Sherman Johnson, Bureau of Agricultural Economics.
3. The Relationship of Industry to Agriculture with Special Reference to the Defense Program. Louis H. Bean, Bureau of Agricultural Economics.
4. Panel Discussion—Agronomic Implications. Charles E. Kellogg, Bureau of Plant Industry.

NEWS ITEMS

DR. STEPHEN KLIMAN, formerly Director of the Wisconsin W.P.A. state-wide-county soil testing project, with headquarters at the College of Agriculture, is now chief soil chemist for the Standard Fruit and Steamship Company of Haiti with headquarters at Port-au-Prince. He will work principally with problems relating to banana culture. DR. DAVIS M. BATSON, who received his Ph.D. degree in soils at the University of Wisconsin last June, has also been employed by the same firm as first assistant to Dr. Kliman.

HARRY P. OGDEN, Associate Agronomist at the Tennessee Agricultural Experiment Station, died recently.

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A NUTRIENT ELEMENT SLIGHTED IN AGRICULTURAL RESEARCH[1]

FREDERICK J. ALWAY[2]

FOR more than a century sulfur has been recognized as an indispensable plant nutrient and for still longer sulfur fertilizers have been used extensively both in this country and Western Europe, but until very recently it has been thought unnecessary to apply sulfur as a fertilizer. The history of the use of sulfur fertilizers may be divided into *three* periods, calling the first the Reign of Gypsum, the second the Reign of Superphosphate, and the third, in which we meet, the Renaissance, or Modern Period. In the first, covering 80 or 90 years, from about 1760 to 1845, gypsum was used widely and its beneficial effects generally overestimated. In the second period, extending into the early part of this century, some 60 years in all, the need of any sulfur additions to the soil was ignored and the use of gypsum discouraged by agricultural scientists. The Modern Period dawned when a Russian chemist, Bogdanov, questioned the assumption that the natural supply of sulfur is everywhere sufficient for crops and three English agronomists, stationed at a county laboratory, put the question to a practical test on local fields. Following the work of these pioneers various localities have been identified in which sulfur-deficiency is common, or at least occasionally appears, but the crops now recognized as the first to show a need of sulfur fertilizer are practically the same as those known in the first period to be most benefited by gypsum.

THE FIRST PERIOD—EARLY USE OF GYPSUM

The earliest part of this period is best described by Pierre, who was professor of general chemistry and agricultural chemistry at the old French university of Caen. In his *Chimie Agricole*, which carries no date of publication, he reports his free public lectures given from 1848 to 1852, devoting some 30 pages to gypsum, other sulfates, and sulfuric acid. I shall quote a few paragraphs:

[1]Address of the President delivered before the thirty-third annual meeting of the Society at Chicago, Ill., December 5, 1940. Paper No. 1864 Scientific Journal Series, Minnesota Agricultural Experiment Station.

[2]Chief of the Division of Soils, University of Minnesota, St. Paul, Minn.

"The use of gypsum appears to have been known since time immemorial in Hanover. However, this use of gypsum began to spread only after the experiments of Pastor Mayer of Kupferzel in (the Swiss canton) Aargau.

"Mayer communicated the results of his experiments to the Economic Society of Bern; these appeared so extraordinary that they had them repeated in the following year before two special commissioners. On the 28th of February, 1768, gypsum was spread on part of a field of clover sown with wheat the preceding spring *on a healthy soil, neither clayey, nor gravelly, nor wet.*

"On May 7 the plastered clover, by its dark green color, distinguished itself in an astounding manner from that which surrounded it.

"Finally, cut on June 17, it was 104 cm. high and very vigorous. That which had not been plastered was (only) 35 to 50 cm. in height and had a yellowish color. Other trials made on a clover sown with oats the preceding year also gave good results.

"The following year (1769) the Commission made other trials on four parcels each of 4,000 square feet. The first received gypsum at the rate of 8 hectoliters per hektare, (about 9 bushels per acre), the second received quicklime at the same rate, the third was given marl at 4 times that rate. . . .

"After this time the use of gypsum spread in a truly extraordinary manner. Introduced into Dauphiny in 1771 it very quickly spread into other parts of France, to England and to Germany. However, it is especially in the United States that the (land) plaster has come into such common use that each year an immense quantity is imported, coming in large part from the quarries of Montmarte, near Paris.

"This introduction of gypsum to the United States dates from a memorable experiment made by B. Franklin. In spreading the plaster on a field of alfalfa situated beside a main road, near Washington, he traced the forever celebrated words: *This has been plastered.* The effect produced on the meadow was such that these words could be easily read by travellers passing on the road."

At the beginning of the nineteenth century according to Graham (1938) the annual import of gypsum into the United States averaged about 30,000 tons but soon climbed to 100,000 tons.

Rothamsted is often credited with the beginning of accurate experimental work with fertilizers, but the second director of that experiment station, Sir Daniel Hall, in his book "Fertilizers and Manures", states that the first man to undertake field experiments on a practical scale was Boussingault, farming his own land in Alsace in 1834. The third and present director of that station, Sir John Russel, in his "Soil Conditions and Plant Growth", uses as frontispiece a picture of Boussingault with the legend "The Founder of Modern Agricultural Chemistry". It is Boussingault that may be given the most credit for bringing the first period to an end, proving, as he believed, that the beneficial action of gypsum is due to its lime content and not to its sulfur. In 1844 he published his treatise "Rural Economy in its Relation with Chemistry, Physics, and Meteorology" and in this devoted much space to gypsum. In the following year

appeared an English translation by George Law. From the latter I should like to read a few quotations.

"... The partisans of gypsum were guilty of exaggeration. They spoke of the substance as an universal manure, capable of supplying the place of every other, as advantageous for every description of crop, as applicable to every variety of soil. Experience soon set bounds to such indiscriminate laudation; it was found that gypsum alone was inadequate to produce fertility that it always required the concurrence of organic manures, if the soil did not contain them of itself; that it only acted beneficially on a certain, and that a very small number of plants; lastly, that it was upon artificial meadows, constituted by clover, lucern, and sainfoin, that it produced its best effects; its action, on the contrary, being scarcely perceptible upon natural meadows, doubtful in connexion with hoed crops and null with the cereals. . . .

"In some places, the number and extent of which are by no means inconsiderable, no good effect whatever has attended the application of gypsum, although it has been administered in favourable conditions and in connexion with crops that elsewhere derive the highest amount of advantage from its use. . . .

"A particular inquiry into the subject was therefore held worthy of its attention by the French government, and a comprehensive report on all the information collected, was made by M. Bosc to the Royal Central Agricultural Society of France."

Boussingault next proceeds to examine critically the then current explanation of the beneficial action of gypsum, one by Davy, the other by Liebig, rejecting both. He writes: "I was, therefore, induced to undertake a series of experiments with a view to study, independently of all hypothetical idea, the action of gypsum upon certain hoed crops and cereals.

"These experiments were made upon patches of land of 440 square yards each. Every precaution was taken to render the experiments strictly comparable one with another."

These plot experiments carried out in 1841, 1842 and 1843, included clover, wheat, oats, rye, and mangolds. As to Liebig's theory that gypsum absorbs ammonia from the rain water and that it is this that benefits plants, he writes: "The action of gypsum, limited as it is to certain crops, will not allow us to admit that it produces its effect by fixing in the ground the carbonate of ammonia contained in rain-water; were it connected with any fixation of ammonia, it would be manifested generally, and not in particular instances only. Davy's theory therefore appears the more plausible, and requires discussion. Did the ashes of the clover grown in gypsed soils actually contain a larger proportion of sulphate of lime, as affirmed by the illustrious English chemist, the action of gypsum would be readily understood. The whole question, therefore, seems to turn upon the composition of the ashes.

"I have analyzed the ashes of clover grown at Bechelbronn, without and with the concurrence of gypsum . . . The ashes of the clover grown upon soil without gypsum contain 6.0 per cent of sulphate of lime; those of clover grown upon a soil with gypsum, 5.7 per cent . . .

"There appears to be no doubt, therefore, that the sulphur required by plants is supplied abundantly by the soil enriched with ordinary manure, as happens in the culture of the cereals, roots and tubers.

"In a word, it may be presumed that Paris-plaster acts usefully on artificial meadows by introducing lime into the soil. This is consistent both with the analysis of the ashes of the crops produced and of the soil."

THE SECOND PERIOD

The lack of interest in gypsum and its mode of action during the following half century and more, a period when agricultural research was developing rapidly in this country as well as in Western Europe, is not to be attributed solely to Boussingault's work. A year before the appearance of his book Lawes had begun the manufacture of superphosphate, which, while providing phosphorus in readily available form, at the same time furnished even more sulfur that was equally available. In practice wherever a fertilizer was used it became superphosphate, either alone or in combination, often with sulfate of ammonia and even sulfates of potash and magnesium. So, incidentally, there was a greatly increased use of sulfur in fertilizers. The concentrated commercial phosphates, double, treble or triple superphosphates, and the metaphosphates had not yet appeared. As all the crops that responded to gypsum, accordingly, did equally well or much better with superphosphate, this new, double-action product drove gypsum out of consideration. During this long period there appears to have been no suggestion that it might be its sulfur content that caused the beneficial action of gypsum, except by Pierre, who mentioned experiments in which sulfuric acid applied to limed soils affected plant growth like gypsum but he doubted if this would be true in the case of soils deprived of lime. Gradually the benefit of gypsum applications came to be attributed to an increase in the availability of the potash in the soil—a base exchange phenomenon.

It is evident that during this second period sulfur in fertilizers was more than merely slighted in agricultural research.

THE MODERN PERIOD

The introduction of this, the Renaissance, is not to be credited entirely to the work of any second Boussingault. Prof. S. M. Bogdanov, a Russian chemist, in 1899 pointed out a probable insufficiency of sulfur in the soil for certain crop plants, after finding more sulfur in these than had been obtained by the older methods—the analysis of the ash. The first confirming field experiments appear to be those of Dymond, Hughes, and Jupe, carried out in 1896 to 1901 in Essex County, England, and reported in 1905 in the first volume of the JOURNAL OF AGRICULTURAL SCIENCE. They compared ammonium sulfate with the chloride and gypsum with no sulfate, using in their field experiments red clover, peas, cabbages, rutabagas, oats, barley, and permanent pasture. The opening and concluding statements in their paper "The Influence of Sulphates as Manure upon the Yield and Feeding Value of Crops" show that the Renaissance was already definitely started:

"An agricultural problem to which little attention has been directed

is the relation of the supply of combined sulphuric acid in the soil to the growth of crops . . .

"There is not sufficient sulphuric acid in the soil or supplied by rain for heavy yielding crops rich in albuminoid, either for the production of greatest yield or the highest feeding value, and for such crops a sulphate should be included in the artificial manure. For cereal crops and for permanent pasture the soil and rain provide all the sulphuric acid necessary."

It fell to the lot of Hart and Peterson in Wisconsin in 1911 to put clearly before agronomists the need of revising their attitude toward the needs of sulfur by crop plants. Preparatory to a study of the relation of wool production to the supply of sulfur in feeds, they acquainted themselves with the work of Dymond, Hughes, and Jupe and the improved methods of determining the sulfur content of plant material that had been developed by a succession of chemists from Berthelot in 1888 to Barlow in 1904. Showing that the crops removed about as much sulfur as phosphorus, they pointed to the small amount in soils, the heavy loss in drainage, and the small amount added in rainwater, as follows:

"It appears that for permanent and increased production of farm crops such systems of fertilization must be inaugurated as will supply to the soil from time to time, in addition to the elements now recognized as necessary, a sufficient quantity of sulfur to meet the losses sustained by cropping and drainage. Such sources of sulfur are farm manures; the trade fertilizers, such as superphosphates, ammonium sulfate and sulfate of potassium; and the so-called soil stimulant, gypsum or calcium sulfate. No attention, so far as we are aware, has been directed to this problem in America."

Two years later Wheeler, in his "Manures and Fertilizers," recognized the changing conceptions, mentioning that sulfur is "one of the elements supposed to be seldom, if ever, so deficient in soils as to require that it be applied artificially," but in view of the facts then known, especially the work of Hart and Peterson, thought the need of sulfur might bear investigating. As to gypsum, he considered that its beneficial effect upon plant growth might in some cases be due to its supplying either lime or sulfur, but that "in general the explanation is more properly to be sought in an indirect manurial action by the virtue of the liberation of other plant food elements."

Shortly after the publication of the Wisconsin work, Powers, Reimer, and Tartar found that on extensive areas in Oregon elemental sulfur, or any fertilizer containing sulfur, causes remarkable increases in the yield of alfalfa and other legumes. Later sulfur-deficient areas have been reported from other states, including Washington, Idaho, California, and Minnesota as well as from the Canadian provinces of Alberta, Saskatchewan, and Ontario.

LOSSES AND GAINS OF SULFUR

The amount of sulfur removed in crops is about equal to that of phosphorus. The late Dr. J. G. Lipman estimated the annual removal of these two elements in crops for the 370 million acres of crop land reported in the 1930 census to average 2.8 pounds of sulfur and 3.8

pounds of phosphorus per acre, with an annual loss in drainage of 41.8 pounds of sulfur but none of phosphorus. The addition of phosphorus in fertilizers to the same 370 million acres he estimated at 3.5 pounds per acre and that of sulfur at 3.9 pounds, thus leaving a deficit, if erosion effects be ignored, of only 0.3 pound of phosphorus per acre compared with a net loss of 28.6 pounds of sulfur, 95 times as much. Averaging all available top soil analyses in the United States, he found for the surface soil (6⅔ inches) only two-thirds as much sulfur as phosphorus, while the annual net loss of the former appears to be 95 times as much. In computing the average net loss of sulfur he omitted the 14.6 million acres of irrigated crop land for which he estimated an annual addition from the irrigation water of 227 pounds per acre of sulfur.

The difference of 16 pounds per acre between the gross and net loss of sulfur is accounted for by 1.5 pounds in manure, crop residues, and seeds, 3.9 pounds in commercial fertilizers, and 10.6 pounds from the rainfall. This estimate of 10.6 pounds per acre per annum from the rain is, I fear, based upon data many of which are misleading, the reported values being too high.

SULFUR IN RAIN AND SNOW

Determinations of the amount of sulfur in the rainfall have been carried out for at least some 90 years. In 1825, Brandes at Salzzufellen in Germany found sulfates in the rain, and in 1851, Pierre computed the amount of sulfur received by the land annually at Caen, a few miles from the English Channel, as 5.8 pounds. In 1852, Angus Smith at Manchester, England, reported finding sulfates in all the rain he examined, the quantity increasing with approach to the town. As general inspector of alkali works for the British Government, Smith was not interested in the beneficial effects of the sulfur in the rain but in its possible harmful effect upon health and its damage to buildings. He found that inland the sulfate content increased as large towns were approached, rising very high in these because of the sulfur in the coal used. In the rain water he found it to vary from a minimum of 0.24 p.p.m. at an inland country place in Scotland to a maximum of 42 p.p.m. in Glasgow. His book "Air and Rain" (1872) appears to have been overlooked by American investigators.

Numerous computations have been reported of the amount of sulfur per acre brought down in the rain, these apparently beginning, except for the single determination by Pierre in 1851 mentioned above, with those from Rothamsted for 1881 to 1887. In this country the amounts have been reported from at least nine states, in some cases calculated from water collected for only a few months, in others for 10 years or more, the annual amounts varying from 232 pounds near a smelter in Tennessee to less than 5 pounds in northern Minnesota. For the 53 stations outside of Minnesota for which I have found data, only 15% are reported as having less than 10 pounds per acre, 22% between 10 and 25 pounds, 46% between 25 and 50 pounds, and 17% still more. I suspect that many of these are too high, but I cannot decide from the information furnished in the

reports just which to thus suspect and I have no intention of asking information from any of the experiment stations as to just how the rainwaters already reported upon were collected for analysis. I know how the collections have been made in Minnesota and I am certain that all the annual amounts I reported at the Chicago meeting three years ago are too high, the error being very high for Minneapolis, decreasing with distance and becoming slight near the headwaters of the Mississippi. Collections and analysis of the snow waters at five of the original Minnesota stations have been continued. The sources of error located lie not in the chemical analysis or in the storage of the samples in glass bottles while awaiting analysis, but in the manner of collection. The concentration of sulfur in the rainwater poured from a rain gage, or other collecting vessel, may at times be even twice as high as that in the rain that entered it only a few minutes before. Further, the amount of sulfur in the water in the gage or other collector, not simply its concentration, may steadily increase with continued exposure to the atmosphere.

DISTURBING EFFECT OF SULFUR DIOXIDE IN THE AIR

Sulfur dioxide is the disturbing agent. It attacks most metal surfaces, including those of zinc, iron, steel, copper, brass, bronze, and alloys of copper with nickel and aluminum, the severity of the attack being affected by humidity, light, and the presence of other chemical compounds. If the metal surface be not protected by a SO_2-resistant coating, sulfates will be formed and these carried down by the next rain will raise the sulfur content of the water submitted to analysis. So it becomes necessary to use collectors of material not subject to corrosion by SO_2, or to protect all metal surfaces with which the rain comes in contact by a coating of some paint or enamel which itself will not contribute sulfur. Water thus collected is satisfactory for analysis if transferred to a stoppered bottle promptly after the rain or snow stops falling; otherwise the SO_2 in the air, if present in sufficient amount, reacts with the water, forming sulfuric acid, the latter increasing with continued exposure. If the water be led from a properly protected collecting funnel directly to a glass bottle, or suitable stoneware jug, by a connection that reduces to a minimum the circulation of air within the bottle or jug, such constant attention becomes unnecessary and collections need be made no oftener than monthly. Rain gages are ordinarily constructed of brass, bronze, copper, or galvanized iron, all corrodible. Those of the U. S. Weather Bureau are designed to measure accurately the rain, not the sulfur in the rain.

Where an open collecting vessel is used, even if of non-corrodible material, and emptied only monthly or bi-weekly, the found amount of sulfur will be too high unless the sulfur dioxide content of the air is very low, the error increasing with the concentration of SO_2 and the rate of movement of the air over the water surface.

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A CONVENIENT METHOD FOR MEASURING THE SO_2 IN THE AIR

As the SO_2 in the air has such a disturbing effect, it is desirable to have some convenient means of measuring its relative amount during

the successive periods of collection. This is provided by the so-called "lead peroxide" method devised by the Department of Scientific and Industrial Research of Great Britain to furnish a measure of the attack of sulfur compounds on building materials. Small cylinders, called "candles", carrying 100 sq. cm. of cotton fabric coated with lead peroxide paste, are exposed freely to the movement of the air while protected from the rain by a cowl or roof. At the end of the month, or more frequently if desired, the peroxide-coated fabric is changed and the amount of sulfate on it determined, correcting for whatever had been in the peroxide coating before exposure.

AMOUNT OF SO_2 IN MINNESOTA AIR

Such candles have been exposed in duplicate at the Minnesota stations for over four years. While the British reports give their data as milligrams of SO_3 per 100 sq. cm. of exposed surface, we express ours as pounds of sulfur per acre. The highest amount we have measured was found on the roof of the building housing the Minnesota section of the U. S. Weather Bureau, located in the heart of the business district of Minneapolis. The total for 12 months was 532 pounds per acre, with a maximum of 74 pounds in November and a minimum of 16 pounds in June. The other extreme is found in northern Minnesota where three stations show an annual absorption of only 3 to 5 pounds with no great difference between summer and winter months, but with every month giving a measurable amount of sulfate. At University Farm, at the edge of St. Paul, the exposures are made only from 300 to 500 yards from the 210-foot stack of a heating and power plant thru which is discharged annually the products of combustion of some 9,000 tons of coal carrying about 135 tons of sulfur. Here the absorption during the summer varies from 5 to 7 pounds a month and in the winter from 18 to 22 pounds, with an annual total of about 120 pounds. In England for the 5-year period ending with March 1938, the annual absorption per acre of exposed surface at Westminster Bridge in London was 591 pounds and at Rothamsted 70 pounds.

RELATION OF SULFUR IN THE RAIN TO SO_2 IN THE AIR

In general, the greater the concentration of SO_2 in the air the higher is the monthly fall of sulfur in the rain, but the relationship is not definite or simple. At Bemidji, where we have the longest record of our northern stations remote from the combustion of large amounts of coal, the annual absorption of sulfur for the past 4 years has been 3.6 pounds per acre and the amount brought down in rain a little higher, 4.5 pounds. At University Farm during the past 12 months, using all the precautions in collection I have suggested, the rain and snow have brought down 12.5 pounds per acre of sulfur while the peroxide surface has absorbed at the rate of 112 pounds, nine times as much. At Bemidji, with its low SO_2 concentration in the air, well-coated metal collectors have shown only a pound per acre less sulfur than the latest U. S. Weather Bureau gage of copper with brass divider and measuring tube. At the same station no significant difference in sulfur was found between two coated copper col-

lectors, one of which was emptied after every storm and the other only at the middle and end of the month. On the contrary, at University Farm, with its high content of SO_2 in the air, both the protection of the metal parts of the collecting vessel and the promptness of emptying water seriously affect the results. An unprotected gage gave twice as much sulfur as did one with all the exposed parts either of coated metal or of glass, both being emptied after every storm. The sulfur taken up by water left two weeks in an open cylinder of coated metal or stoneware has been found to exceed even that brought down in the rain during the same interval.

So far as concerns the reliability of published data on the addition of sulfur to the soil by the rain, I suggest that the high values be regarded with extreme suspicion, unless it can be established that the collecting vessel did not present a corrodible surface to the water and also that the rain or snow was transferred from the collecting vessel promptly after each rain or fall of snow. The lowest values, on the contrary, may be considered not far astray, even if these two precautions were not observed.

A RUSSIAN STUDY OF PRECIPITATION

The most important paper on the amount of sulfur in precipitation, in my opinion, is that by Kossowitsch which appeared in 1913 in the Russian Journal of Experimental Agronomy. He had collections of the precipitation made at eight stations in European Russia during 1909, 1910, and 1911; at one station for only 9 months, at another for 2½ years, and at the others for periods intermediate between these extremes. One station was at the Agricultural Institute in St. Petersburg and a second at the nearby Forestry Experiment Station, and at both the annual amount of sulfur found was 28 pounds per acre. At an observatory 19 miles south of the city only 6.1 pounds were found. At four stations remote from both cities and coal burning factories very low annual amounts were found, *viz.*, 3.8, 2.6, 3.2, and 2.7 pounds per acre, the respective distances of these stations from St. Petersburg, all to the south or southeast, being about 45, 350, 600, and 950 miles. At the Forestry Experiment Station near the industrial city of Mariupol, on the Sea of Azov, also about 950 miles southeast of St. Petersburg, the amount was 20 pounds per acre. There is no information as to the character of the collectors used. Collections of the water were made at least monthly. There appears no reason to suspect that the low values reported for the four remote stations are too low. The high values for the three stations near the cities may or may not be high.

CONCLUSION

If the annual fall of sulfur in rain and snow at stations in Russia remote from coal-burning towns is less than 4 pounds per acre and at stations in northern Minnesota is only 4 or 5 pounds, what may we find elsewhere *in the open country* in North America? The amount of sulfur in the soil is low and its loss in drainage is high over much of this country. Its chief replenishment is from the air, but as to the extent of this replenishment we have but little information.

THE USE OF TENSIOMETERS FOR FOLLOWING SOIL MOISTURE CONDITIONS UNDER CORN[1]

M. B. Russell, F. E. Davis, and R. A. Bair[2]

SEVERAL workers (2, 3, 5)[3] have recently shown that tensiometers may be used successfully in studying certain soil moisture problems. The instruments have a particular advantage where it is desired to obtain a continuous record of soil moisture conditions at several depths without disturbing the soil after the original installations have been made. During the summers of 1938 and 1939 soil moisture conditions under growing corn (maize) were followed by the use of tensiometers in conjunction with other studies on the interrelations among meteorological environment, soil conditions, crop response, and yield of corn.[4]

THE EXPERIMENTAL FIELDS

The soils of the field in which the plots were located in 1938 varied considerably. The southwestern part of the area was located on Clarion loam, the central part on Webster loam, and the central and southeastern parts were mapped as Webster silt loam. The locations of the tensiometer installations with respect to the soil type are shown in Fig. 1. The elevations at each installation site with respect to the central installation are:

Central location 0

West + 0.75 foot	East −1.74 feet
South − 1.31 feet	Southeast − 2.80 feet

The soils of the area on which the plots were located in 1939 also showed considerable variation. The texture graded from Clarion loam in the southwest corner of the field to Webster loam in the central section and to Webster silty clay loam in the eastern third of the area. The soil boundaries and tensiometer sites are shown in Fig. 1. The elevations at each installation site with respect to the elevation of the southwest installation are:

Southwest 0	Southeast − 3.53 feet
West central − 0.89 foot	East central − 3.95 feet
Northwest − 1.16 feet	Northeast − 4.38 feet

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[3]Figures in parenthesis refer to "Literature Cited", p. 930.

[4]This study is a cooperative project between the Iowa Agricultural Experiment Station and the U. S. Department of Agriculture under Bankhead-Jones Special Research Funds and was conducted on the Agronomy Farm at Ames, Iowa. The authors wish to acknowledge aid given by Dr. L. A. Richards, under whose supervision the original installations were made.

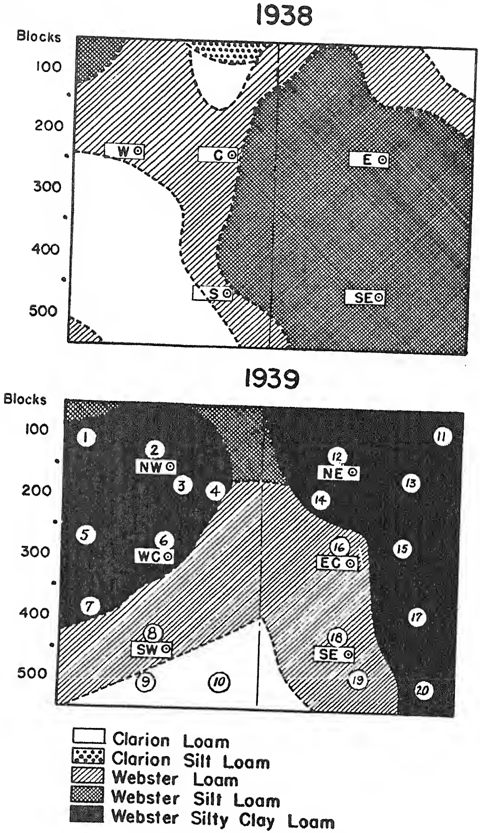

FIG 1.—Tensiometer locations and soil boundaries of the 1938 and 1939 fields.

The values for the permanent wilting percentage in Table 1 are the average of duplicate determinations made on each of the samples taken at the 6-, 18-, and 36-inch levels at each of 20 locations in the 1939 field. The location of the samples in the field are shown in Fig. 1. These permanent wilting percentage values tend to confirm the observed textural gradation in the surface soil of the area.

TABLE 1.—*The permanent wilting percentage of samples from three depths at each of 20 random locations.*

Location No.	6 inch depth	18 inch depth	36 inch depth	Location No.	6 inch depth	18 inch depth	36 inch depth
1	11.4	14.3	10.8	11	18.6	18.4	13.9
2	14.6	17.2	13.9	12	17.2	15.4	9.0
3	13.6	15.6	11.4	13	18.0	15.5	13.1
4	13.0	17.2	11.5	14	17.0	14.5	8.1
5	13.7	16.0	18.3	15	18.1	15.5	11.0
6	14.3	15.5	11.6	16	19.1	17.2	8.9
7	12.3	11.8	6.8	17	18.1	15.9	12.0
8	12.8	12.4	9.0	18	15.1	16.7	14.3
9	10.9	14.9	14.3	19	12.5	14.6	8.4
10	10.8	11.9	9.6	20	17.3	16.3	13.4

Volume weight determinations also were made at various depths in the area. The data are summarized in Table 2. These determinations were made from soil samples of known volume and were obtained by the use of a sampling tube having a $\frac{13}{16}$-inch bore. The samples were taken at random locations in the field at weekly intervals throughout the summer of 1939. A significant difference was observed in the volume weight of the surface 6 inches between the southwest and the northeast quarters of the field. The mean volume weight and standard error of the former was $1.391 \pm .035$ and of the latter $1.239 \pm .027$.

TABLE 2.—*Volume weight of soil from different depths.*

Sample depth, inches	Number of samples	Vol. weight, grams/cc
0–6	215	$1.308 \pm .014$
6–18	215	$1.315 \pm .0084$
18–30	203	$1.387 \pm .0079$
30–42	203	$1.555 \pm .0078$
42–54	79	$1.661 \pm .017$

THE TENSIOMETER INSTALLATIONS

The tensiometers were of the spout-top type that has been described elsewhere (1). The tensiometer manometers were mounted on individual wooden stakes driven in the ground about 2 feet from the installations. A special stainless steel scale was devised with which it was possible to read the tension directly in centimeters of mercury.[5] The scale was graduated in units of 1.08 cm, since it has

[5]These scales may be purchased from the College Instrument Shop, Iowa State College, Ames, Iowa.

been shown (2) that the height of the mercury column in a tensiometer manometer is 8% greater than the tension if the latter is to be expressed in centimeters of mercury. The tensiometers were installed at the desired depths with the aid of a soil auger having the same taper as the porous cups. The porous cup must make good contact

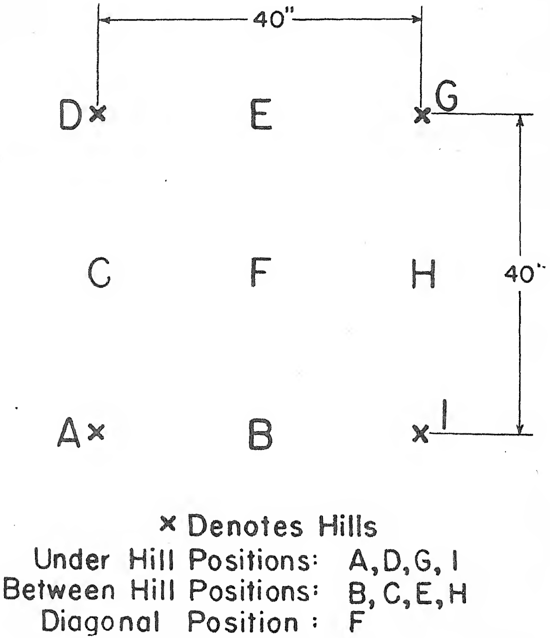

FIG. 2.—Positions of tensiometers with relation to hills of corn at the central location in the 1938 field.

with the soil, and therefore the auger holes were carefully made. After the tensiometers were placed in the auger holes, soil was tightly packed around the upper end of the tensiometer tubes to prevent water from following down the outside of the tubes to the porous cups. Some trouble was experienced with air leaks that developed at the connections between the rubber and copper tubing. Leaks of this kind were accompanied by a reaction between the copper and

rubber, probably the formation of copper sulfide. It is thought that this trouble may be eliminated by protecting the ends of the copper tubes by bakelite or chromium plate.

In the spring of 1938, tensiometers of the type described above were installed at five locations in the 2-acre test area as indicated in Fig. 1. At each location four tensiometers were installed at the depths of 12, 24, 36, and 60 inches at a position equidistant from four adjacent hills of corn, as position F in Fig. 2. This position will be hereafter referred to as the diagonal position. At the central location in the field, Fig. 1 C, additional tensiometers were installed at 6-, 12-, and 24-inch depths under each of the four adjacent corn hills and at positions midway between each pair of corn hills as shown in Fig. 2. Under two corn hills additional cups were installed at depths of 36 and 48 inches.

In 1939, installations were made at the 12-, 24-, 36-, 48-, and 60-inch depths at each of six locations in the test area as shown in Fig. 1. At each location the tensiometers were placed in the diagonal position, equidistant from four adjoining corn hills as in 1938.

EXPERIMENTAL RESULTS

The relation between the tension of the soil water and the moisture content of the soil has been studied previously for several soils and has been shown to depend on several factors, principal of which are texture and structure of the soil and the previous soil moisture conditions (4). As has been pointed out above, the soil in which the tensiometers were installed possesses considerable variation in texture at different depths as well as at different locations in the field. Consequently, a moisture sorption curve for each of the soil types represented would be required to interpret the tension readings in terms of soil moisture percentages. Although the soil variability largely precludes the possibility of an accurate conversion to moisture percentages in the field, it does not interfere with studies of moisture moving forces or moisture availability inasmuch as these phenomena are dependent primarily upon the tension of the soil water.

The data obtained from the 34 tensiometers installed at the central location in the 1938 field gave a rather complete picture of the moisture conditions beneath the four corn hills. The zones from which the corn roots progressively absorbed moisture during the summer of 1938 are indicated by the data summarized in Fig. 3. It will be seen that the tension readings began to increase rapidly first at the 6-inch level, then at the 12-inch level, 24-inch level, and 36-inch level at successively later dates. At each level the tensiometer beneath the corn hill was the first to show the effects of lowered soil moisture content, followed or accompanied by tensiometers at successively greater distance away from the corn plants. These data indicate that the zone of moisture absorption begins at a shallow depth directly beneath the corn plant, then spreads until a major portion of the available moisture at that depth has been used. Next, the zone of absorption extends to a greater depth where it once more expands from a point directly beneath the corn plants until finally the available moisture at this depth is also exhausted. In the area studied in

1938 the zone of extensive moisture depletion extended roughly to the 48-inch depth.

The above information on the zone of moisture absorption indicates that the placement of the tensiometers in relation to the corn plants is important. Where interest centers on the comparison of

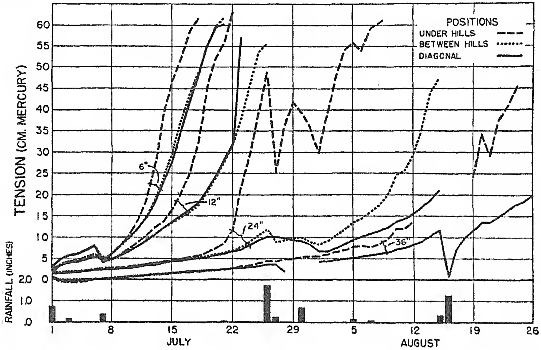

FIG. 3.—Tensions at four depths and three positions throughout the 1938 season at the central location.

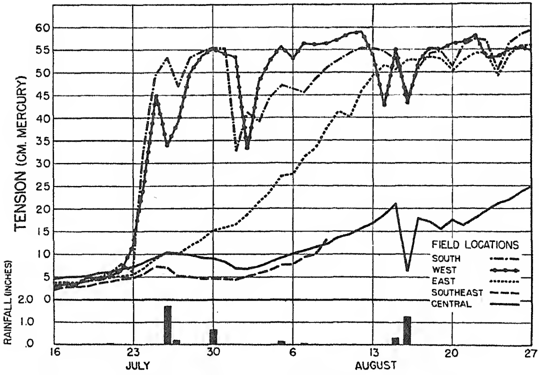

FIG. 4.—Tensions at the 24-inch depth at five field locations in 1938.

soil moisture conditions from year to year, as in the case of the project from which the present data are taken, the diagonal position of the tensiometers appears superior. The moisture at this position represents the last of the reserve at any given depth, and it is the depletion of such reserves that foreshadows critical moisture conditions for the plants.

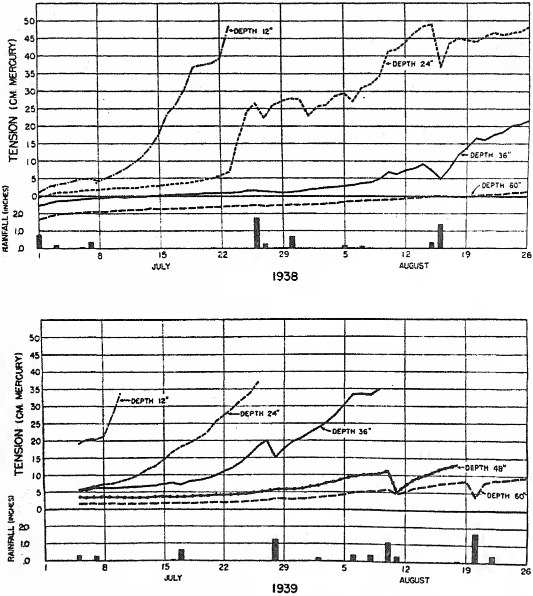

FIG. 5.—Tensions at various depths at the diagonal position for 1938 and 1939, average of all locations in the field.

Fig. 4 shows that wide differences occurred between the tensions recorded at corresponding depths at the several locations in the field. During the early part of the growing season the tension readings at all locations were in close agreement. As the transpiration load increased, however, the moisture content of the soil was decreased at each part of the field in a manner similar to that described above. Fig. 4 shows that the date at which the zone of extensive moisture

absorption reached the 24-inch level was quite different at the several tensiometer locations. The tensions at the south and west locations rose at an earlier date than did those of the other locations. This was due in part to the lower moisture storage capacity of the lighter textured surface soil in the southwestern part of the field. Other contributing factors may have been differences in crop growth, differences in elevation, and different transpiration conditions caused by unequal exposure to the prevailing winds. In 1939, similar differences were recorded between tensiometers installed at the several locations in the field.

Data from tensiometers installed in the diagonal position at each location in the fields are summarized in Fig. 5. The curves indicate that in both 1938 and 1939 the corn obtained its moisture from successively greater depths as the growing season progressed. It may be seen, however, that although the curves for 1938 and 1939 are of the same type, comparable rapid tension rises occurred at much earlier dates in 1939 than in 1938. These differences may be attributed to the larger size of the corn plants at any given date in 1939 as compared with their size on the same date in 1938. In 1939 the corn was planted on May 8, whereas in 1938 it was planted on May 24.

Fig. 5 also reveals differences in the depth of the free water table in 1938 and 1939. Negative tension values indicate that the tensiometer cup is below the free water table and consequently is subjected to a pressure greater than atmospheric. Fig. 5 shows that the free water table was about the 60-inch depth until August 15 in 1938, whereas in 1939 the water table was below the 60-inch depth during the entire period of measurement. Under conditions where soil moisture is at static equilibrium under gravity, the distance from a tensiometer cup to the free water surface may be calculated from the manometer reading. Such a calculation indicates that on August 15, 1939, the water table was 97 inches below the soil surface as compared to a depth of 60 inches at the same date in 1938.

CONCLUSIONS

1. Tensiometers installed at depths ranging to 60 inches at several locations in 2-acre fields successfully followed soil moisture conditions under corn during the 1938 and 1939 growing seasons.

2. Corn roots first absorbed moisture at a shallow depth directly beneath the corn hills. The zone of absorption extended laterally until most of the available moisture at that depth was depleted. The lateral expansion of the moisture absorption zone occurred at successively lower depths as the growing season progressed.

3. Because of the character of the zone of moisture depletion, the position of the tensiometers with respect to the corn hills influenced the type of information secured. Data from the cups installed equidistant between four adjacent corn hills were the most reliable for making year to year comparisons of soil moisture conditions.

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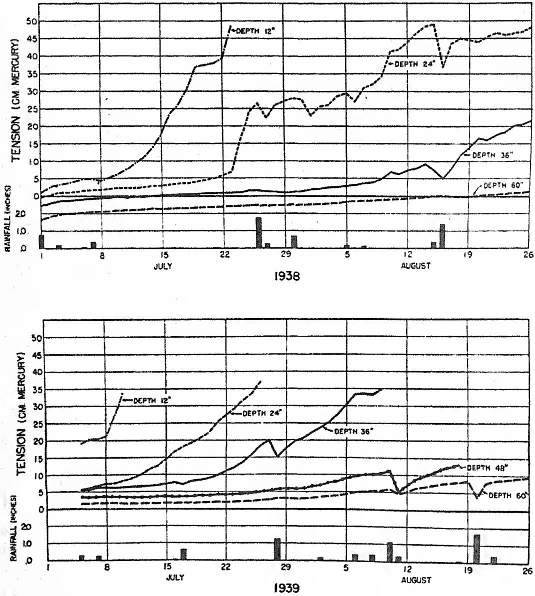

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THE EFFECT OF SELECTION AND INBREEDING ON THE GROWTH OF BIG BLUESTEM (*ANDROPOGON FURCATUS*, MUHL.)[1]

ALVIN G. LAW AND KLING L. ANDERSON[2]

ANDROPOGON furcatus, commonly called big bluestem or bluejoint turkey foot, is one of the most valuable native perennial forage species in the tall grass or prairie region of the United States. It is found throughout the temperate region of North America (12)[3], although it is most important in the Flint Hills or bluestem pasture section of eastern Kansas and Oklahoma where, together with *A. scoparius*, it constitutes more than half of the total vegetative cover.

During the past two decades there has been a continued decline in the carrying capacity of the native grass pastures as a result of over-utilization. This condition, accentuated by the low rainfall of recent years, has focused attention on the native grass species from the standpoint of obtaining superior strains for restoring depleted pastures. In the development of such strains it is essential that the plant breeder possesses a knowledge of the variability and inheritance of the characters with which he must work. To this end studies of *A. furcatus* were initiated in 1935 by the Department of Agronomy of the Kansas Agricultural Experiment Station.

REVIEW OF LITERATURE

Various authors (1, 4, 8, 22) have adequately discussed the importance of *Andropogon furcatus* from the standpoint of forage production, palatability, and erosion control. It is an extremely variable species, exhibiting definite habitat groups that are distinctly different. Turesson (21) has drawn attention to the fact that species in nature contain certain groups which, primarily by reason of the selective influence of their environment, express a phenotypic constitution suited to the conditions of life in their particular habitats.

Gregor and Sansome (9) agreed with Turesson that there may exist in species definite habitat types and concluded that, although phenotypic uniformity was frequently attained by these wild populations, they were quite variable genetically and under the more severe eliminating influence of artificial selection such habitat types could again be separated into different growth habit groups.

Anderson and Aldous (2), working with *Andropogon scoparius*, found considerable genotypic variation within ecotypes but much greater variation between ecotypes.

In his work with *Lolium perenne*, Jenkin (13) concluded that, while individual plants from a fairly stable habitat might differ from one another phenotypically, the genotypic variation would usually be much greater. He found that plants from different habitats conformed to distinct general growth types.

[1]Contribution No. 309, Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kans. Received for publication September 21, 1940.

[2]Formerly Graduate Research Assistant and Assistant Professor of Pasture Improvement, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 943.

A partial explanation of the extensive variability exhibited by *Andropogon furcatus* may be found in the fact that the species is highly cross-pollinated (3), and consequently exhibits a variety of types. Furthermore, its chromosome number may vary. Church (6) reported the somatic chromosome number as 70, while Nielsen (17) found a type having 60 somatic chromosomes. Church (7) later found tetraploid and hexaploid forms of this prairie species having 40 and 60 chromosomes, respectively, and noted the relationship between polyploidy and the wide transcontinental range of *A. furcatus*. He reported diploid species of American *Andropogon* as occuring only along the Atlantic coastal plain in contrast to the wide range of the higher polyploid species and concluded that the greater stability of temperature and soil moisture of the coastal plain has contributed to this restriction of the diploids.

Inbreeding results in a depressive effect on the vigor of many cross-pollinated species. Significant reductions in plant height, winter hardiness, and seed production were reported by Nilsson (18) for *Festuca pratensis*, Huds., *Dactylis glomerata* L., and *Phleum pratense* L.

Stapledon (20) observed a loss of 50% in vegetative vigor of *Dactylis glomerata* following inbreeding which closely agrees with the work of Calder (5) on this species.

Jenkin (13) found a 63% loss of vigor as a result of inbreeding *Lolium perenne*.

Various workers (10, 11, 16) have reported much variation in the response of *Phleum pratense* to inbreeding, some lines being greatly reduced while others were as vigorous as the open-pollinated selections.

Williams (23) obtained a marked and a progressive loss in vigor as a result of inbreeding red clover but found some lines that were more vigorous than others. These, he found, were valuable for the production of improved strains by crossing since they tended to be strongly prepotent for high yield.

The effect of self-pollination on seed set of many grass species has been investigated by various workers. Anderson and Aldous (2) found that inbreeding reduced seed set of *Andropogon scoparius* 49 to 57%. Nilsson (18) obtained a range of 0–5% of normal seed set in inbred *Festuca pratensis* and a variation from complete self-sterility to self-fertility in *Dactylis glomerata* and *Phleum pratense*. Kirk (15) reported reduced seed set in selfed *Bromus inermis*, *Dactylis glomerata*, and *Lolium perenne*. Jenkin (14) encountered complete self-sterility in some *Lolium perenne* families and concluded that self-sterility was one of the greatest obstacles in the breeding of grasses.

MATERIAL AND METHODS

The breeding work on *Andropogon furcatus* was started in 1935 at the Kansas Agricultural Experiment Station at Manhattan when the first generation, consisting of 200 individual plants, was set out for detailed observation. The seed for this nursery was obtained under conditions of open pollination from small, adjacent observation plots which were, in turn, grown from seed of particularly promising plants, most of which were found growing in a droughty location along an old railroad grade near Manhattan.

Five generations of selection in open-pollinated material in its first year of growth have been included in this study with additional observations on the second year growth of the first four generations. The second generation consisted of progeny from each of the original 200 plants. The third, fourth, and fifth generations consisted of progeny from selected plants of each preceding generation. In 1938, selections were made from the 1937 nursery plants in their second year of

growth to be compared with the selections made from the same plants in their first season of growth. Each generation of seedlings was started in the greenhouse in February and transplanted to the field nursery in May. The plants were all spaced 30 inches each way to reduce competition among them and to permit cultivation for weed control. Such an arrangement made possible the detailed observation of individual plants and permitted furrow irrigation during the drier part of the summer.

Detailed field notes were taken each year during the growing season and the maternal parents selected on the basis of these observations. Since 1937 a number of heads on several of the most promising plants have been bagged in parchment sleeves to study the effect of inbreeding, the inbred progeny to be compared to their open-pollinated sibs. These heads were allowed to mature within the bags and were harvested in October at the time the open-pollinated seed was collected.

During the fall and winter caryopsis counts were made on representative samples from each of the plants to determine the percentage seed set. Germination tests were made by planting the seed in moist soil in the greenhouse and covering it with a quarter of an inch of clean sand. After germination counts were obtained the seedlings were spaced into flats, 2 inches apart, 100 seedlings to each flat, and later spaced out in the nursery.

EXPERIMENTAL RESULTS

GENERAL VARIABILITY

Andropogon furcatus exhibits a wide range of adaptation to many soil types and to a variety of climatic conditions. Strains from Nebraska, Kansas, and Oklahoma grown in the Manhattan nursery indicate there are definite ecotypes in this species which have developed as a result of natural selection over a long period of time. In general, the northern plants are earlier, smaller, and less leafy than those of southern origin, while the plants from Kansas are intermediate in these characters. The average heading date of the Nebraska plants was 21 days earlier than that of the Kansas plants, while the Oklahoma plants headed 47 days later than those from Kansas. Variations equally as great can be seen in leafiness, number of culms, and height. Fig. 1 shows the difference in growth habit of typical plants from these three strains.

Within ecotypes of *Andropogon furcatus* there are also definite natural variations in many characters. Although it is not as obvious as the variation between ecotypes, this variability can be perceived readily upon close observation of any one ecotype. It is this variation that has been utilized in the selection of superior lines from the Manhattan ecotype.

EFFECT OF SELECTION ON LEAFINESS

Leafiness is the most important single consideration in the selection of a superior plant of *Andropogon furcatus*. Total leaf area of the individual plants at their most leafy stage was calculated by multiplying average length of leaf by average width, by average number of leaves per culm, and by total number of culms in the manner described by Anderson and Aldous (2). This gave a value consider-

ably greater than the actual leaf area, but it was found to be satisfactory for purposes of comparison. The actual leaf area of each leaf as determined by planimeter measurements of 100 leaves selected at random was shown to be 68.1% of the calculated area.

The data relative to the effect of selection on the leaf area of *Andropogon furcatus* are presented in Table 1.

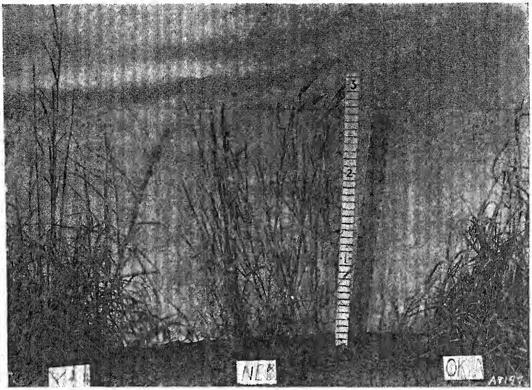

FIG. 1.—Variation in growth habit, leafiness, and time of maturity of *A. furcatus* plants grown in the Manhattan, Kansas, nursery from seed obtained in Kansas, Nebraska, and Oklahoma.

TABLE 1.—*The effect of continued selection on the leaf area of Andropogon furcatus*

Generation	Nursery	No. of plants	Mean and standard deviation (sq. cm.)	Coefficient of variation	Analysis of variance: F value*	Analysis of variance: 1% level of significance
			First Season of Growth			
1st	1935	197	1296±910	70	—	—
3rd	1937	510	5237±2970	57	4.36	1.57
4th	1938	250	7497±3584	48	2.20	1.88
5th	1939	100	12986±6665	51	1.62	2.59
4th†	1939	120	10095±7407	73	3.89	2.40
			Second Season of Growth			
1st	1935	197	14160±9350	65	—	—
2nd	1936	190	26004±10309	40	3.07	2.31
3rd	1937	250	46703±20350	44	3.67	1.88
4th	1938	330	36697±12980	35	2.38	1.77

*Obtained by dividing variance between lines by variance within lines.
†Selection from second year growth, third generation (1937 nursery).

The highly significant F values of the early generations, obtained when comparing variation between progeny groups to that within progeny groups, would indicate there were distinct differences in the ability of the maternal parent plants to transmit the character leaf area to their progeny. It should be possible in such a population to bring about considerable improvement by continued selection of the desirable types from open-pollinated lines. The yearly means in Table 1 show highly significant increases in leaf area of the progeny groups in both their first and second seasons of growth following four generations of selection in open-pollinated lines. The slight advantage of the third generation over the fourth in the second season of growth is probably due to seasonal variation.

The general variability of the population has been decreased materially during the course of the experiment as is shown by the trend of the coefficients of variation in the successive selected generations. This is due, in a large measure, to the reduced variation between different progeny lines brought about by continued selection of similar individuals. It has been possible to eliminate a large percentage of the undesirable types leaving a population whose range of variability is narrowed somewhat. This conclusion is substantiated by the results of analyses of variance which show a distinct reduction in differences between lines compared to differences within lines.

From Table 1 it can be seen that there has been decidedly less total variation between plants in their second season of growth as compared to the same plants in their first season of growth. In analyzing data relative to the variability between individual plants exclusive of any variation between progeny groups, it was found that plants in their first season of growth gave an average coefficient of variation of 43% compared to 34% for the same plants in their second season of growth. Since the plants in their second season of growth exhibit less inter-plant variation, they should present more reliable material from which to make selections. To secure information relative to this point, selections were obtained from the third generation (1937 nursery) in both its first and second seasons of growth and the progeny from these two selections compared as to yield (Table 1). The data show a marked advantage for the selections from 2-year-old plants. This is especially important in view of the fact that the F values for the fifth generation selections indicate that there are no longer any significant differences between progeny groups of plants selected in their first season of growth. Selection in five successive generations toward a common type has resulted in the elimination of extreme types and has narrowed the range of variability in the population as a whole. Thus, the plants tend to be more like one another than is the case in unselected material. For this reason they must be grown long enough to permit full expression of their phenotypes before careful selections can be made, and the data indicate that further open-pollinated selection in such first-year material would be expected to yield little, if any, increase in leaf area. However, it would appear possible to extend the usefulness of selection in open-pollinated lines by careful choice of plants in their second year of growth.

EFFECT OF SELECTION ON NUMBER OF CULMS, BASAL DIAMETER, AND PLANT HEIGHT

Extensive data have been obtained relative to the effect of selection in open-pollinated lines on number of culms, basal diameter, and plant height. In each case it has completely substantiated the conclusions reached regarding the effect of selection on leafiness. For example, it has been possible to increase the mean number of culms per plant from 57 ± 29 to 148 ± 49 by four generations of selection. At the same time variability in this character, as measured by the coefficient of variation, has decreased from 51 to 33%.

In regard to plant height, it was felt that the extremely tall and extremely short plants were undesirable from a forage standpoint and consequently these types have been eliminated by the selection program. During the four generations of selection, average plant height at the most leafy stage of growth was reduced from 52 ± 8 to 30 ± 6 inches. Plants in their second season of growth were not significantly taller than they were in their first season of growth. Also, the variability in this character has been much lower throughout the experiment than that for leaf area and number of culms.

Basal diameter has been increased significantly by selection. However, because of the difficulty in obtaining accurate measurements and because of the extremely small differences between plants in this character, it has not been considered important in the selection program. Analysis of variance studies of number of culms, plant height, and basal diameter show that after the fifth generation of selection there were no longer any significant variations between progeny rows, whereas earlier generations had shown highly significant differences between lines. These facts emphasize the necessity of a more intensive method of breeding under conditions of controlled pollination if further improvement is to be accomplished.

EFFECTS OF INBREEDING

Inbreeding in *Andropogon frucatus* is accompanied by considerable loss of vigor in most of the inbred lines that were observed. In 1938, reductions in leaf area of 60 and 71% for the S_1 and S_2 generations, respectively, were obtained when inbred progeny were compared to their open-pollinated sibs. Similar figures were found for number of culms, maximum height, and basal diameter. In each character there is evidence that continued inbreeding is followed by a progressive decline in vigor. There is, however, considerable variation in the response of different lines to inbreeding, as is shown in Table 2. It is significant that the open-pollinated lines having the largest leaf areas have been reduced the most following inbreeding. Moreover, the inbred lines that have suffered little loss of vigor in S_1 have given progeny lines (S_2) that likewise are quite vigorous. This variation in response to inbreeding is shown in Figs. 2, 3, and 4.

A most obvious effect of inbreeding has been the segregation of the inbred sibs into rather distinct entities, making for greater variation between lines than is found in the open-pollinated sibs. For example, in the S_2 lines (1939 nursery) there is a highly significant

TABLE 2.—*Differences in size of various inbred progeny groups in comparison with their open-pollinated sibs (1938 nursery).*

Parent plant Nos.	Mean leaf area (average of 10 plants)			
	Open-pollinated		Inbred sibs	
	Mean and S. D.	Coefficient of variation	Mean and S. D.	Coefficient of variation
1	9244±3299	35	1118±810	72
2	8028±2422	30	2275±770	33
3	5287±2538	48	774±692	89
4	5939±1699	28	1041±514	50
5	5161±1917	37	1063±737	69
6	5160±2418	47	3185±937	29
7	6125±3307	54	3851±1687	43
8	4617±1741	37	2240±829	37
9	6193±1705	27	5019±5039	100+
10	5519±2585	46	5608±3938	70

F value of 7.37 (1% level of significance = 2.23) as compared to 1.62 (5% level of significance = 1.97) for the open-pollinated lines. Furthermore, there is considerable heterosis evidenced by the open-pollinated progeny of S_2 lines. These progeny show a mean leaf area of 13,794±6,721 sq. cm. compared to 2,192±1,696 sq. cm. for the maternal parents and 12,986±6,665 sq. cm. for the open-pollinated lines that have undergone five generations of selection for increased leaf area. Thus, it would appear that careful selection, inbreeding, and recombination of the inbred lines would be a logical method of strain building for *Andropogon furcatus*. These observations have been substantiated by data obtained on number of culms, basal diameter, and plant height which for the sake of brevity are not presented in this paper.

TIME OF MATURITY

Time of maturity, as measured by the appearance of the first five culms bearing inflorescences, has shown no significant change following four generations of selection of late-maturing maternal parents in open-pollinated lines. Sufficient data are not available to explain this failure to obtain late-maturing lines. It was observed that progeny rows from early-maturing parent plants have approximately the same average date of maturity and exhibit about the same range of variability as progeny from late-maturing plants. On an average, it requires nearly 35 days for a plant to complete the flowering process so there would be ample opportunity for pollen from the later flowers on an early plant to fertilize the earlier flowers on a late plant. The progeny from such a cross would vary for flowering date. There is some evidence that time of maturity is conditioned by length of day and temperature so that plants from a single ecotype would tend to head at about the same time, variations being caused by such factors as competition between plants, soil and moisture

variations, and various injuries resulting from transplanting and cultivation.

Inbreeding has affected the time of maturity of *Andropogon furcatus* only in so much as it has reduced the vigor of certain plants to the point that they were unable to produce heads. The inbred

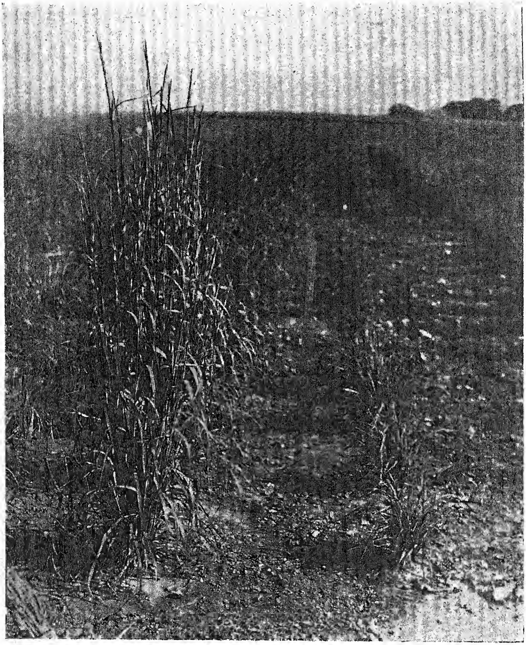

FIG. 2.—Extreme loss of vigor following two generations of inbreeding *A. furcatus* shown by the inbred row on the right in contrast to the open-pollinated sib on the left.

plants that were vigorous enough to flower did so at the same time as their open-pollinated sibs. About 45% of the inbred plants in the 1938 nursery failed to head at all in their first season of growth due, apparently, to the extremely weak condition of many of the plants. A similar percentage of the inbred plants in their first season of

growth failed to head in 1939. No such definite segregation between lines in time of maturity could be observed in the inbreds as was found for total leaf area, number of culms, basal diameter, and plant height.

SEED PRODUCTION AND GERMINATION

Extreme variability has been observed in the amount of seed set as measured by the percentages of caryopses per spikelet. Data regarding this character are shown in Table 3. In 1939, seed set in the

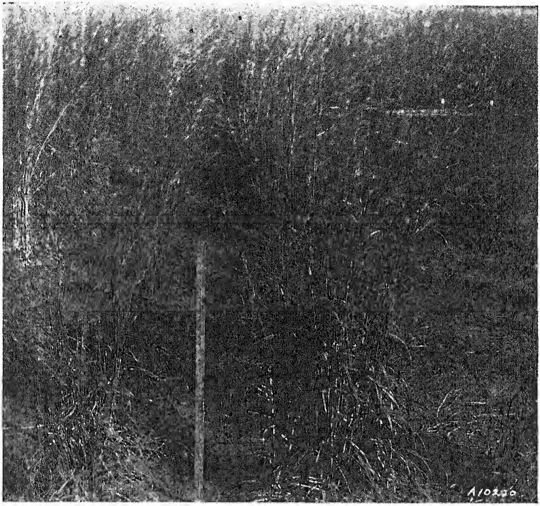

FIG. 3.—Moderate loss of vigor following two generations of inbreeding *A. furcatus* shown by the inbred row on the left in contrast to the open-pollinated sib on the right.

open-pollinated plants ranged from 0 to 84% of the spikelets filled. The later plants mature more seed, as a rule, since most of the heads that appear early in the season are blasted by the hot, dry winds of late July and August.

It was also evident that the most desirable plants from a forage standpoint are not the best seed producers. A line selected for high total yield, quality, leafiness, and uniformity gave an average seed set of $31 \pm 8.06\%$ compared to $52 \pm 11.01\%$ for a coarse, non-leafy strain.

TABLE 3.—*Percentage of spikelets filled in A. furcatus, 1937–39, inclusive.*

Treatment	Number of caryopses per 100 spikelets (av. of 300)				Average
	Open pollinated	Inbred, 1936*	Inbred, 1937	Inbred, 1936–37	
		Seed Obtained in 1937			
Open-pollinated	45.9 ±20.70	50.59±21.07	—	—	48.25
Inbred........	7.03± 7.37	8.76±10.07	—	—	7.89
		Seed Obtained in 1938			
Open-pollinated	17.56± 9.71	15.63± 9.33	13.30± 9.42	9.95± 8.65	14.11
Inbred........	1.11± 1.62	0.33± 0.61	1.93± 3.18	2.70± 3.32	1.51
		Seed Obtained in 1939†			
Open-pollinated	37.40±14.52	37.30±13.56	25.10±17.82	20.10±15.07	30.20
Inbred........	7.40± 6.20	10.60± 9.20	4.50± 6.43	3.40± 3.18	6.47

*Heads enclosed in cheesecloth bags which were not pollen proof.
†Selections from plants in their second season of growth (1938 nursery).

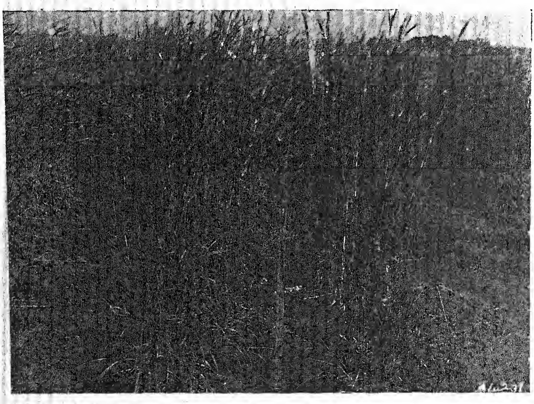

FIG. 4.—No loss of vigor following two generations of inbreding *A. furcatus*. Inbred row on the right, its open-pollinated sib on the left.

Inbreeding in *Andropogon furcatus* has resulted in reductions of as much as 84% in seed set under the selfing bags in the first inbred generation, while subsequent inbred generations have shown even greater reductions (Table 3). Whether this progressive decline in seed set is due to increased self-sterility following inbreeding or to the greatly reduced vigor of the inbreds, or to both factors, can not be determined from the available data. A range in seed set of the

inbreds from 0 to 42% would indicate that unfavorable conditions under the bag are of little importance in determining the percentage of seed set. Although self-sterility appears to be the rule, a few lines have been found that are highly self-fertile.

There have been no significant differences between germination percentages of the open-pollinated and inbred plants of *Andropogon furcatus*, nor has the time of seedling emergence varied significantly between the open-pollinated and inbred sibs. However, there has been considerable inter-plant variation in these characters that may be important from the standpoint of selection.

INTERRELATIONSHIPS OF CHARACTERS

Highly significant inter-annular correlations have been observed in each of the characters of leafiness, number of culms, basal diameter, plant height, and time of maturity, indicating that there are definite factors that interact with the environment to determine the expression of these characters.

A second group of correlations measuring the relationship between two variates is shown in Table 4. Various factors, such as the age of the plant, the effect of selection, and environmental conditions, may affect these values. It will be noted that leaf area and number of culms are most closely related, although leaf area and plant height show highly significant correlations in each of the years. Furthermore, there was no significant correlation between number of culms and plant height except in the unselected material. This would be expected since the number of culms was increased and plant height

TABLE 4.—*The correlation of various factors in A. furcatus.*

Nursery	Year of data	No. of culms	Maximum height	Time of maturity	Basal diameter
			Leaf Area		
1935	1935	——	0.288±0.065	——	——
1937	1937	0.766±0.028	0.405+0.049	0.304±0.005	——
1937	1938	0.778±0.018	0.352±0.040	0.236±0.024	——
1938	1938	0.662±0.036	0.307±0.037	−0.211±0.037	——
1938	1939	0.673±0.030	0.405±0.046	0.101±0.054*	——
1939	1939	0.695±0.052	0.257±0.093	−0.108±0.061*	——
			Plant Height		
1935	1935	0.496±0.054	——	——	——
1937	1938	0.017±0.033*	——	——	——
1938	1938	−0.036±0.055*	——	−0.279±0.049	——
1938	1939	0.113±0.017*	——	——	——
1939	1939	−0.117±0.099*	——	−0.167±0.057*	——
			Number of Culms		
1937	1938	——	——	——	0.331±0.041
1938	1938	——	——	——	0.486±0.048
1938	1939	——	——	——	0.408±0.040
1939	1939	——	——	——	0.478±0.069

*Not significant.

decreased by continued selection. Time of maturity shows no consistent relationship with leaf area, although early in the experiment the later plants were also the most leafy. Number of culms and basal diameter, as would be expected, were significantly correlated throughout the experiment.

SUMMARY AND CONCLUSIONS

Andropogon furcatus is one of the most important native forage species of the tall grass area of the United States. Investigation of the genetic behavior of this species with a view to the development of improved strains by open-pollinated selection was started in 1935 at the Kansas Experiment Station. The species was found to be extremely heterozygous in nature and to be divided into definite habitat groups or ecotypes which, in turn, were highly variable within themselves. This highly variable condition would be expected since the species is a polyploid of remote hybrid origin having a variable chromosome number and is highly cross-pollinated. The effects of selection and inbreeding on the variability and growth of a Manhattan, Kansas, ecotype are discussed.

That the variability of *Andropogon furcatus* is controlled by genic interaction with the environment is shown by the fact that highly significant variations have been found between progeny groups of different plants. Furthermore, by five generations of selection in open-pollinated lines of desirable plants as maternal parents, it has been possible to increase leaf area more than 22,000 sq. cm. for plants in their second season of growth and more than 12 times for plants in their first season of growth. At the same time, there has been a significant decrease in the variability of the population so that further improvement by selection in first season of growth material is not likely. The data indicate that it will be necessary to resort to selection in second and third year material to reach the ultimate degree of improvement by this method.

Extensive data obtained regarding number of culms, plant height, and basal diameter substantiate the conclusions reached from the study of leaf area.

Inbreeding is accompanied by a marked and progressive loss of vigor in most of the lines studied. However, there is considerable variability in the response to inbreeding. Some inbred lines were found that showed no reduction in vigor when compared to their open-pollinated sibs and other inbred lines were so lacking in vigor that they failed to survive the first season.

Continued selection of late-maturing plants as maternal parents has not significantly changed time of maturity nor has inbreeding affected this character except in so much as it has reduced the vigor of many of the plants to the point that they were unable to produce heads. The inbred plants that were able to head did so at the same time as their open-pollinated sibs.

Seed production, as measured by the percentage of spikelets containing caryopses, has shown much variability that is apparently influenced by the genetic constitution of the plant. Seed set is greatly reduced following inbreeding and there are indications that this re-

duction is due to genetic factors rather than any abnormal condition within the bags. Germination has not been affected by inbreeding nor has the time of emergence of the seedlings varied significantly between open-pollinated and inbred sibs. Significant inter-annular correlations have been found for each of the characters—leaf area, number of culms, plant height, basal diameter, and time of maturity. Significant positive correlations of leaf area to number of culms and plant height were found, but leaf area and time of maturity exhibited no definite relationships. Also, there were no significant correlations between plant height and number of culms except in the unselected material.

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FIELD GERMINATION OF ALFALFA SEED SUBMITTED FOR REGISTRATION IN COLORADO AND VARYING IN HARD SEED CONTENT[1]

RALPH M. WEIHING[2]

HARD or impermeable seeds which commonly occur in alfalfa are those that do not absorb water (swell) and germinate under laboratory conditions standard for determining germination of alfalfa seed. These seeds, for the most part, are alive and when planted in the field may produce healthy seedlings, but there are differences of opinion as to their agricultural value for planting. Since alfalfa seed offered for sale often contains high percentages of hard seeds, it is desirable to know the comparative planting value of seed containing high and low percentages of hard seeds.

The results of a study conducted under irrigation on the Agronomy Farm of the Colorado Experiment Station at Fort Collins, Colorado, to determine the agricultural value of alfalfa seed varying from 1 to 62% of hard seeds are presented in this paper.

LITERATURE

Harrington (1)[3] states, "A large proportion of impermeable alfalfa,. . . . seeds will germinate in the soil during the first few months after planting, some of them early enough to be of importance to the crop," and recommends, "To the percentage of germination add two-thirds of the percentage of impermeable seeds . . . . More than two-thirds of the impermeable seeds may germinate, but not soon enough to compete with weeds."

Leggatt (2) concluded that hard seed of alfalfa had practically the same value from the point of view of number of plants produced as had the permeable, although the permeable seeds gave more prompt germination. Lute (4) found that "Impermeable seeds have a considerable agricultural value when there is a very high impermeable seed content," "They do not increase the number of plants when only a few are present," and "They germinate more slowly than other seeds."

Whitcomb (6) says, "These results with alfalfa would seem to indicate that the hard seeds are of practically the same value as plant producers in the field as the ordinary seeds." He confirms this viewpoint in later papers (7, 8, 9). This investigator (10) later states, "Half the hard seeds may be safely added to the laboratory germination of alfalfa, ... for the purpose of interpretation of the field value of these seeds."

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[1]Contribution from the Agronomy Section, Colorado Experiment Station, Fort Collins, Colo. Published with the approval of the Director as Scientific Series Paper No. 110. Received for publication September 30, 1940.

[2]Assistant Agronomist. For the first two years this study was conducted by Mr. John Spencer and Mr. Wayne Austin, formerly with the Colorado Seed Registration Service, and now with the Soil Conservation Service, U. S. Dept. of Agriculture.

[3]Figures in parenthesis refer to "Literature Cited", p. 949.

MATERIALS AND METHODS

The seed was obtained from samples submitted by Colorado seed growers to the Colorado Seed Registration Service. Laboratory germination tests of these samples were made by the Colorado State Seed Laboratory.[4] Seeds which did not swell after 6 days at 20° C between moist blotters were considered hard or impermeable, while percentage germination was based on sprouted seeds. Four hundred seeds of each sample were tested in the laboratory.

Seed from samples tested in the laboratory during the winter was planted the following spring in the field. Lute (5) from her studies made the following general conclusions: "One-half of the impermeable alfalfa seeds when kept in storage became permeable in three and one-half years" and "All impermeable seeds of alfalfa in storage became permeable in 11 years." This suggests that a few of the seeds found to be hard during the winter were permeable when planted in the field in the spring. Sixty-seven laboratory-tested samples which varied from 1 to 62% in hard seed content were planted in the field. Spring field plantings of 22, 27, 12, and 6 samples were made in 1932, 1933, 1938, and 1939, respectively.

Three hundred seeds of each sample were planted in the field 1 inch deep and 1 inch apart in rows 12 inches apart. The 300 seeds of each sample were planted in three plots (100 seeds in each plot) arranged at random within replications. In 1932 the number of plants was counted 10, 28, and 43 days after planting, and in 1933 similar counts were made 31 and 77 days after planting. This technic did not give true emergence of seedlings since some plants were killed by insects or other agencies before and between counting days. In 1938 and 1939 a small stake was placed beside each seedling shortly after emergence so that the actual number of seedlings which emerged was obtained even though some plants died before termination of the experiments.

The dates of planting were May 3, May 7, May 3, and April 28 in 1932, 1933, 1938, and 1939, respectively.

RESULTS

The data for six samples tested in the laboratory during the winter of 1938–39 and planted in the spring of 1939 are given in Table 1. The percentages of hard seeds varied from 14 to 54, but 10 days after planting, emergence of seedlings was nearly the same for all samples, varying from 54 to 62%. Seventeen days after planting, emergence

TABLE 1.—*Laboratory and field germination of alfalfa seed, 1939.*

Laboratory germination, winter of 1938–39			Field emergence of seedlings after		
Hard seeds, %	Germination, %	Total, %	10 days, %	17 days, %	35 days, %
14	80	94	62	69	70
22	74	96	62	64	64
30	63	93	54	60	65
41	54	95	56	66	74
49	45	94	55	65	68
54	41	95	54	62	66

[4]The tests were made by Anna M. Lute, Seed Analyst, Colorado Experiment Station.

varied from 60 to 69%. Thirty-five days after planting, emergence in the sample containing 14% of hard seeds exceeded that in the sample containing 54% by only 4%.

TABLE 2.—*Laboratory and field germination of alfalfa seed, 1938.**

Laboratory germination, winter of 1937–38			Field emergence of seedlings after					
Hard seeds, %	Germination, %	Total, %	8 days, %	14 days, %	22 days, %	28 days, %	36 days, %	48 days, %
1	96	97	36	70	73	73	73	74
15	76	91	23	52	55	55	55	60
25	58	83	24	48	51	51	52	57
28	63	91	18	45	50	51	51	57
30	57	87	27	51	57	57	58	61
34	58	92	25	54	60	62	62	70
35	59	94	23	48	53	54	54	61
38	55	93	24	55	61	62	62	66
44	49	93	15	48	53	55	55	61
47	47	94	19	44	50	51	52	61
52	43	95	19	47	53	54	54	65
55	44	99	16	49	54	56	56	61

*One irrigation 38 days after planting.

TABLE 3.—*Laboratory and field germination of alfalfa seed, 1933.*

Laboratory germination, winter of 1932–33			Plants in field after	
Hard seeds, %	Germination, %	Total live, %	31 days, %	77 days, %
5.5	85.0	90.5	47	47
8.0	82.0	90.0	43	38
9.0	86.0	95.0	51	45
13.0	77.0	90.0	49	45
25.5	66.0	91.5	40	36
29.5	69.0	98.5	58	54
30.5	61.0	91.5	33	41
32.0	60.5	92.5	41	37
33.0	56.5	89.5	55	47
34.5	61.5	96.0	54	45
37.5	57.5	95.0	38	33
38.0	52.5	90.5	47	45
39.0	54.0	93.0	45	43
39.0	56.5	95.5	55	48
40.0	57.0	97.0	52	44
42.0	49.5	91.5	44	40
43.5	49.5	93.0	41	39
44.5	43.5	88.0	46	42
44.5	46.5	91.0	48	43
47.0	54.5	91.5	36	33
48.0	48.0	96.0	53	48
49.0	46.5	95.5	36	31
49.5	39.0	88.5	45	44
53.0	47.0	100.0	45	38
57.5	39.0	96.5	47	41
61.0	36.0	97.0	39	39
62.0	29.5	91.5	46	46

Percentage of hard seeds in samples tested in the laboratory during the winter of 1937–38 and planted in the spring of 1938 varied from 1 to 55 (Table 2). At the end of the test, 48 days after planting, the number of emerged seedlings was highest for the sample containing 1% of hard seeds, but it was nearly equal for samples varying from 15 to 55% of hard seeds. However, emergence was more rapid in samples with few hard seeds than in samples with many hard seeds. By two weeks after planting, emergence was practically the same for nearly all samples.

The counts of plants 31 and 77 days after planting in 1933 (Table 3) show that all samples of seed produced about equal numbers of plants even though the samples varied in hard seed content from 5.5 to 62.0%. The 1932 field results (Table 4) show that 4 weeks after planting samples varying from 4 to 57.5% hard seeds produced about equal numbers of plants. Ten days after planting (Table 4) emergence was greater for samples with few hard seeds than for those with many. This advantage was lost 4 weeks after planting.

TABLE 4.—*Laboratory and field germination of alfalfa seed, 1932.*

Laboratory germination, winter of 1931–32			Plants in field after		
Hard seeds, %	Germination, %	Total, %	10 days, %	28 days, %	43 days, %
4.0	90.0	94.0	62	68	67
11.0	84.5	95.5	67	77	77
12.0	88.5	100.5	64	73	69
22.0	63.0	85.0	45	55	55
24.0	66.0	90.0	65	69	70
28.0	67.0	95.0	54	65	61
37.0	59.0	96.0	53	68	66
37.0	57.0	94.0	57	63	63
37.5	54.0	91.5	55	69	66
38.5	53.5	92.0	60	72	73
40.5	55.5	96.0	54	64	63
40.5	55.5	96.0	56	71	68
41.0	47.0	88.0	43	53	54
43.0	48.0	91.0	45	60	58
43.5	56.0	99.5	54	65	66
47.0	50.5	97.5	58	66	66
47.0	47.0	94.0	50	58	53
48.5	42.5	91.0	46	55	54
50.5	39.5	90.0	58	69	67
53.5	42.0	95.5	45	59	61
57.0	39.0	96.0	51	71	67
57.5	40.0	97.5	48	63	61

Plant counts were made in 1932 and 1933, while emergence records were made in 1938 and 1939. Since some seedlings and plants die in the field because of insect injury and other causes, the last plant count in the season may be lower than preceding ones. This actually happened in the two years, 1932 and 1933, that plant counts were made. The abnormally small number of plants in 1933 probably was caused by such injury. In 1938 and 1939 approximately 50% and 15%, respectively, of the plants died after emergence so that

plant counts in those years would have been 50% and 85% of the emergence values.

The data in Tables 1, 2, and 4 show that 70% emergence in the field rarely was exceeded, even though some samples germinated more than this amount in the laboratory. This observation has been made by other investigators so that it seems that 70% emergence is as much as can be expected even under favorable field conditions.

The data for the 4 years are summarized in Table 5 to show the percentage germination[5] in the field for samples which had 0 to 9%, 10 to 19%, 20 to 29%, 30 to 39%, 40 to 49%, and 50 to 62% of hard seeds in the laboratory tests. Samples with less than 20% of hard seeds germinated 61 to 64%, whereas samples with 20% or more hard seeds germinated 57 to 60% on the average. Slightly better germination can be expected in the field from seed with few hard seeds than from seed with many.

TABLE 5.—*The comparative field germination of samples of alfalfa seed varying from 1 to 62% of hard seed.*

Hard seed, %	1939*		1938*		1933†		1932‡		Germination, %	
	No. of samples	Germination, %	No. of samples	Germination, %	No. of samples	Germination, %	No. of samples	Germination, %	3-year av.	4-year av.
0–9	—	—	1	74	3	47	1	68	63	—
10–19	1	70	1	60	1	49	2	75	61	64
20–29	1	64	2	57	2	49	3	63	57	58
30–39	1	65	4	61	8	46	4	68	58	60
40–49	2	71	2	64	9	45	8	62	57	60
50–62	1	66	2	63	4	44	4	66	58	60

*Percentage germination based on total emergence for the season.
†Percentage germination based on plants present 31 days after planting.
‡Percentage germination based on plants present 28 days after planting.

SUMMARY AND CONCLUSION

The data show that samples of seed with 20 to 62% of hard seeds produced about equal numbers of plants in the field. These samples averaged 57 to 60% germination. Samples with less than 20% hard seeds averaged 61 to 64% germination, slightly higher germination than for samples containing 20% or more of hard seeds.

Emergence was more rapid for samples of seed with few hard seeds than for those with many, but 2 to 3 weeks after planting all samples had nearly equal numbers of plants.

The data indicate that under favorable field conditions not more than 70% emergence can be expected for samples of seed germinating nearly 100% in the laboratory.

Alfalfa seed containing many hard seeds has almost the same agricultural value for planting as alfalfa seed containing few hard seeds.

[5]Emergence in 1938 and 1939, number of plants 28 days after planting in 1932, and number of plants 31 days after planting in 1933.

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RELATIVE PRODUCTIVITY OF THE A HORIZON OF CECIL SANDY LOAM AND THE B AND C HORIZONS EXPOSED BY EROSION[1]

Earle E. Latham[2]

THE Piedmont Plateau Soil Province of South Carolina comprises a considerable variety of soils of which the Cecil series is the most extensive and one of the most valuable for general farming. It is well adapted to the production of cotton which is the chief source of farm income in this area.

Cultivated areas of Cecil sandy loam, before being materially altered by erosion, have a yellowish-gray or grayish-brown surface soil and a red clay subsoil which is underlain by highly weathered, disintegrated granite or gneiss. The topography where these soils occur varies from undulating to rolling or hilly. The sloping terrain in combination with high rainfall (approximately 50 inches annually) and the use of farming methods conducive to accelerated erosion have resulted in extensive soil loss by water erosion. In some places these soils have eroded to such an extent that their agricultural value has been destroyed entirely.

There are large acreages of Cecil soils in which the A horizon has been removed entirely by erosion, leaving the red clay of the B horizon exposed. Fair crops are frequently produced on such areas, and it is possible in many places to improve them by additions of organic matter and the use of suitable farming practices to such an extent that high yields of crops can be obtained. There are also extensive areas on which both the A and the B horizons have been removed by erosion. When the A and B horizons are eroded they cannot be re-formed or replaced by practical agricultural methods. There remains only the highly unproductive weathered rock, which is not classed as a soil but only as the material from which one may be developed when subjected to soil-forming processes for a long period of time. Field observations of a qualitative nature have shown that erosion of the surface soil causes a decrease in productivity of Cecil soils, but there are no quantitative data available showing the extent of this relation.

Experiments designed to obtain some information regarding the relative productivity of different horizons of Cecil sandy loam were started near Moore, S. C., in 1935.

Twelve experimental areas, each 1/500 acre in size (10 feet by 8 feet, 9 inches), were marked off and excavated to a depth of 2 feet. Each area was enclosed in a creosoted board wall extending to the bottom of the excavation. Soil from the A horizon of Cecil sandy loam was collected from 40 different locations in the South Tyger River Project Area, transported to the desired location, placed in a pile, and mixed. The soil from the B horizon was collected and mixed in

[1]Contribution of the Soil Conservation Service, Office of Research, in cooperation with the South Carolina Agricultural Experiment Station, Clemson, S. C. Received for publication October 2, 1940.

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a similar manner. The soil in each case was obtained from areas where the horizon desired had been exposed to the atmosphere for a considerable period of time, that is, the B horizon was obtained where the A horizon had already been removed by erosion. The C horizon material was likewise collected from a number of locations where it had been exposed for a considerable length of time. There were four plots for each horizon. The A horizon plots were prepared by placing 12 inches of B horizon material on the bottom of each pit and 12 inches of A horizon material on top of it. The B horizon plots contained only B horizon material and the C horizon plots only C horizon material or weathered rock. All plots were prepared during the summer of 1935.

In the spring of 1936 these plots were fertilized at the rate of 400 pounds per acre of 4–12–4 fertilizer and planted to cotton. The fertilizer was applied under the beds prior to planting. Each plot contained the same number of rows and received the same treatment. The cultural treatments received by the plots were similar to those practiced by farmers in this area. Photographs of these plots taken the latter part of August (Fig. 1) show the relative cotton growth on the plots of each horizon.

In 1937, 1938, and 1939 all plots were again planted to cotton with an annual fertilizer application of 400 pounds per acre of 4–8–4 in 1937 and 4–10–4 in 1938 and 1939. In addition to the fertilizer application in 1939, two plots of each horizon received manure at the rate of 4 tons per acre. The manure was broadcast over the plots the same day the cotton was planted. The annual yields of seed cotton and the averages for the 4-year period are given in Table 1.

TABLE 1.—*Productivity of different horizons of Cecil sandy loam as determined by cotton yields at Moore, S. C.*

Horizon	Yield of seed cotton per acre, pounds*				
	1936	1937	1938	1939	Average
A	1,610	1,241	345	561	939
B	235	501	132	348	304
C	75	113	83	51	81

*These data are averages of four plots for each horizon with the exception of 1939 when only the two plots of each horizon not receiving manure were included.

The results show wide variations in yield from year to year within each horizon which were undoubtedly influenced to a great extent by seasonal conditions. The low yields of the A horizon after 1936, however, indicate that the soil decreased in productivity during the experiment. Yields on the B and C horizons were low at the beginning of the experiment and remained so throughout the test. If the 4-year average yield of the A horizon is compared with the yield from the B horizon, a difference of 635 pounds of seed cotton is noted in favor of the A horizon plots. Likewise, the A horizon showed an average yield of 858 pounds more of seed cotton than the C horizon. The average yield for the B horizon was 223 pounds more than the C

horizon. The results of this study emphasize the importance of conserving the A horizon of surface soil for farming purposes. The low

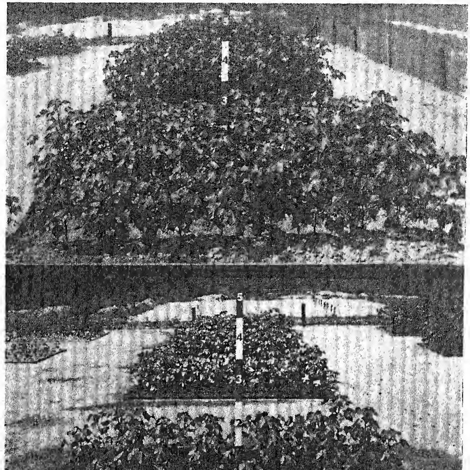

FIG. 1.—Growth of cotton on A, B, and C horizons (reading from the top down) of Cecil sandy loam in August 1936.

yields from the B and C horizons were probably due largely to lack of an adequate supply of nitrogen and other nutrients, as the soil of these horizons is very infertile until improved by suitable farming practices.

The influence of stable manure upon cotton yields on the A, B, and

TABLE 2.—*Cotton yields on different horizons of Cecil sandy loam, showing the influence of manure in 1939 following three years of continuous cotton without manure.**

Horizon	Plot Nos.	Treatment	Yield of seed cotton per acre, pounds			Treatment†	Yield of seed cotton per acre in 1939, pounds
			1936	1937	1938		
A	1 and 3	Unmanured	1,536	1,227	356	Manured	845
	2 and 4	Unmanured	1,684	1,254	335	Unmanured	561
B	1 and 3	Unmanured	242	461	89	Manured	501
	2 and 4	Unmanured	228	541	175	Unmanured	348
C	1 and 3	Unmanured	106	131	105	Manured	426
	2 and 4	Unmanured	44	188	61	Unmanured	51

*All plots received inorganic fertilizer each year.
†The manure treatments in 1939 were at the rate of 4 tons per acre.

TABLE 3.—*Boll counts of cotton grown on different horizons of Cecil sandy loam, showing the percentage open on October 28, 1936, as an index of earliness of maturity.*

Horizon	Plot No.	Bolls per plot, number	Open bolls per plot on Oct. 28	
			Number	%
A	A-1	247	76	30.8
	A-2	321	142	44.3
	A-3	326	152	46.6
	A-4	304	175	57.6
Average		300	136	45.3
B	B-1	73	0	0.0
	B-2	110	2	1.8
	B-3	127	1	0.8
	B-4	104	6	5.8
Average		104	2	1.9
C	C-1	52	10	19.2
	C-2	50	2	4.0
	C-3	36	2	5.6
	C-4	28	2	7.1
Average		37	4	10.8

C horizons of Cecil sandy loam is shown in Table 2. The manure caused a substantial increase in cotton yields on all horizons, but its effect was most pronounced on the C horizon. In Table 2 the plots have been arranged in duplicate for each year, corresponding to the manure-treated plots of 1939. The manure had a beneficial effect on the survival of plants on the C horizon but did not noticeably affect the survival of cotton plants on the other horizons.

Data in Table 3 were collected in order to obtain some idea as to the number of bolls produced and the earliness of maturity which is important under boll weevil conditions. The cotton bolls opened earlier on the A horizon than on the B or the C horizons. Practically one-half, or 136 bolls, on the A horizon were open October 28 when the counts were made, as compared with two and four open bolls on the B and C horizons, respectively.

SUMMARY

In summarizing the results it may be stated that under the conditions of this experiment the A horizon was more than 3 times as productive as the B and 11 times as productive as the C horizon. Additions of organic matter in the form of stable manure resulted in increased yields on all horizons. The beneficial effect of manure on the C horizon was relatively greater than on the other horizons.

The results from the manure treatments indicate that the productivity of eroded Cecil soils may be greatly improved through the addition of organic matter and an adequate supply of plant nutrients.

GENETICS OF CROSS-INCOMPATIBILITY AMONG SELF-INCOMPATIBLE PLANTS OF *TRIFOLIUM REPENS*[1]

SANFORD S. ATWOOD[2]

A KNOWLEDGE of the genetics of cross-incompatibility is of fundamental interest in any species and should be one of the first prerequisites to the intelligent planning and pursuing of a practical breeding program. This character has been investigated in a large number of species, as reviewed by Stout (5),[3] but only Williams (6) has made extensive observations with white clover. He reported (a) that unrelated plants generally are reciprocally cross-compatible, (b) that sister plants are either reciprocally cross-incompatible (c. 26% of his crosses) or reciprocally cross-compatible, and (c) that compatible F_1 sister crosses on the average seemed to produce as many seeds as crosses between unrelated plants.

MATERIALS AND METHODS

The original parents used in this investigation were two highly self-incompatible plants, one of which came from a seed lot collected in Michigan while the other was clonally isolated from a pasture in Pennsylvania. The cross between these two plants was made in the greenhouse during the winter of 1937–38, and the F_1 was grown in the field the following summer at which time 13 plants were selected for greenhouse study. These plants were similar to their male parent in having a solid white area on their leaflets, thus indicating that they were legitimate hybrids, since the marking is dominant over the solid green color of the female. The principal basis for selection among both F_1 and F_2 plants was their general vigor and paucity of disease. Also, wherever possible, plants were chosen which flowered well in the field, since it had been observed in the winter of 1937–38 that the plants which flowered best in the greenhouse were those plants which had flowered well the summer before in their first year's growth in the field. Practically all the controlled cross-pollinations were made in screened greenhouses during the winter. The technics used for emasculating and pollinating, as well as those for cross-pollination with bees and for self-pollination under bag, will be described in another publication.

EXPERIMENTAL RESULTS

The two parents and their F_1 were self-pollinated in several ways (tripping 10 flowers per head, with and without emasculation, and rubbing entire heads) and at different times to measure their self-compatibility. The largest average number of seeds set on one parent under all treatments was 1.8 per head and on the other 1.6. A similar degree of self-compatibility was shown by 14 F_1 plants, which yielded

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[2]Agent.

[3]Figures in parenthesis refer to "Literature Cited", p. 968.

TABLE 1.—*Number of seeds set per 10 flowers in all reciprocal combinations between 13 self-incompatible sister plants (1–3 to 1–15) resulting from the previous cross between a self-incompatible female (1–1) and male (1–2) parent, together with the reciprocal back-crosses of each F_1 plant with both parents.*

		♂															
♀ Genotype	Plant No.	1–I (S_1S_2)	1–II (S_3S_4)	1–III (S_1S_3)					1–IV (S_2S_3)				1–V (S_1S_4)			1–VI (S_2S_4)	Average of compatible crosses
		1–1	1–2	1–3	1–4	1–5	1–7	1–9	1–10	1–11	1–13	1–15	1–8	1–12	1–14	1–6	
1–I(S_1S_2)	1–1	0	51	42	48	47	45	(50)*	43	44	43	46	45	(39)	48	49	45.7
1–II(S_3S_4)	1–2	52	0	50	47	52	51	51	51	47	50	46	54	(49)	53	(51)	50.3
1–III(S_1S_3)	1–3	47	51	0	0	0	3†	1†	48	55	52	38	51	54	43	51	49.0
	1–4	42	41	0	0	0	0	0	35	41	43	43	(47)	41	48	37	41.8
	1–5	30	43	0	0	0	0	1†	35	36	(41)	39	38	43	31	38	37.4
	1–7	46	46	0	0	2†	2	0	51	44	50	42	50	42	(41)	43	45.5
	1–9	46	39	0	0	1†	0	1†	37	45	42	47	35	49	38	43	42.1
1–IV(S_2S_3)	1–10	40	38	36	41	32	36	39	0	1†	0	0	36	(41)	39	40	38.0
	1–11	51	14	48	46	52	47	44	0	0	0	0	51	53	44	42	47.8‡
	1–13	50	43	46	(50)	45	43	48	1	0	1†	1†	48	50	47	54	47.6
	1–15	45	40	49	48	46	40	44	0	0	0	2†	45	44	41	43	44.1
1–V(S_1S_4)	1–8	48	51	42	54	49	48	54	52	47	(50)	51	1†	2†	0	47	49.4
	1–12	41	(40)	36	28	(33)	41	35	28	36	37	31	0	0	0	38	35.3
	1–14	(38)	53	55	54	49	49	53	48	49	52	46	2†	4†	0	(49)	49.6
1–VI(S_2S_4)	1–6	49	45	55	45	49	44	46	50	48	46	47	48	48	42	1†	47.3
																	44.9‡

*Numbers in parenthesis in this and the following tables recording seed set have been adjusted to a 10-flower basis. For instance, if a pod was lost at harvesting, the total number of seeds obtained was increased by 1/9. In no case have less than eight flowers been available.

†Duplicate cross yielded 0 seed.

‡The seed set in cross 1–11 × 1–2 was omitted from average. This is abnormally low because of poor pollination. The duplicate cross was lost.

	1–III	1–IV	1–V	1–VI	Total
Expected	3.25	3.25	3.25	3.25	13
Obtained	5	4	3	1	

from 246 heads under bag in the field an average seed-set of 1.7 per head and whose individual averages ranged only from 0.6 to 4.6. Very few white clover plants have been found which will not yield an occasional seed when a large number of heads are selfed. On the other hand, plants have been found which are just as self-compatible as they are cross-compatible. Comparatively speaking, the plants used in this investigation may be considered practically self-incompatible.

TABLE 2.—*Number of seeds set per 10 flowers when F_2 plants from cross 1–III × 1–IV (1–7 × 1–11) were back-crossed to P and F_1 groups.*

Genotype	Plant No.		1–I (S_1S_2)	1–II (S_3S_4)	1–III (S_1S_3)	1–IV (S_2S_3)	1–V (S_1S_4)	1–VI (S_2S_4)	Average of compatible crosses
1–I(S_1S_2)	1–17	♀	0	50	51	55	52	53	52.2
		♂	0	(42)	30	49	43	47	
	1–20	♀	0	44	43	40	40	28	39.0
		♂	0	—	—	—	—	—	
	1–23	♀	0	51	(47)	41	49	57	49.0
		♂	0	31	43	34	36	—	
	1–86	♀	3	50	38	33	—	—	40.3
		♂	0	40	45	38	48	—	
	1–90	♀	—	—	—	—	—	—	—
		♂	0	—	23	19	—	—	
1–IV (S_2S_3)	1–16	♀	39	46	39	0	36	32	38.4
		♂	—	—	—	0	—	—	
	1–18	♀	34	36	33	0	26	33	32.4
		♂	—	—	—	0	—	—	
	1–19	♀	24	22	15	0	29	31	24.2
		♂	—	—	—	0	—	—	
	1–21	♀	47	50	28	0	37	52	42.8
		♂	46	—	—	2	—	—	
	1–22	♀	33	35	21	0	28	31	29.6
		♂	—	—	—	0	—	—	
	1–24	♀	31	47	34	0	42	35	37.8
		♂	—	—	—	0	—	—	
	1–25	♀	53	32	44	0	40	50	43.8
		♂	—	—	—	0	—	—	
	1–87	♀	43	34	—	0	—	—	38.5
		♂	48	48	38	1	37	51	
Average of compatible crosses			47.0	40.2	35.8	35.0	41.0	49.0	39.2

	1–I	1–IV	Total
Expected:	6.5	6.5	13
Obtained:	5	8	

The 13 selected F_1 plants consisted of four intra-sterile, inter-fertile groups of five, four, three, and one, respectively, and every F_1 plant was reciprocally fertile with both parents (Table 1). Every combination was made in duplicate, and a few were made three or

TABLE 3.—*Number of seeds per 10 flowers when F_2 plants from cross 1–III × 1–V (1–7 × 1–8) were backcrossed to P and F_1 groups.*

Genotype	Plant No.		1–I (S_1S_2)	1–II (S_3S_4)	1–III (S_1S_3)	1–IV (S_2S_3)	1–V (S_1S_4)	1–VI (S_2S_4)	Average of compatible crosses
1–II (S_3S_4)	1–26	♀	2*	1	41	50	50	49	47.5
		♂	44	0	44	40	48	30	
	1–27	♀	0*	1	0*	0*	0*	0*	—
		♂	—	0	—	—	—	—	
	1–28	♀	41	0	43	40	51	58	46.6
		♂	48	0	51	48	46	42	
	1–30	♀	46	0	40	0*	28	0*	38.0
		♂	—	0	—	—	—	—	
	1–31	♀	46	0	0*	1*	(23)	44	37.7
		♂	—	1	—	—	—	—	
	1–32	♀	0*	0	40	0*	39	18	32.3
		♂	—	1	—	—	52	—	
	1–33	♀	20	0	23	34	39	49	33.0
		♂	47	0	28	40	52	—	
	1–91	♀	—	0	—	—	—	—	—
		♂	44	1	40	49	52	—	
	1–93	♀	0*	0	23	36	—	—	29.5
		♂	51	0	41	48	49	—	
	1–94	♀	(8)*	0	—	18	10	—	14.0
		♂	—	0	—	lost*	24	—	
	1–95	♀	16	0	30	20	37	29	26.4
		♂	46	0	32	(50)	47	46	
I–V(S_1S_4)	1–29	♀	44	53	45	46	0	34	44.4
		♂	43	—	—	—	0	—	
	1–34	♀	30	41	51	49	1	51	44.4
		♂	—	—	—	—	0	—	
	1–35	♀	48	50	47	45	0	13*	47.5
		♂	—	—	—	—	1	—	
Average of compatible crosses			46.1	—	40.7	45.8	46.2	39.3	40.6

*Cross was recorded compatible by reflection of pedicels on third day after pollination. This abnormally low seed set was omitted from average for plant.

	1–II	1–V	
Expected:	7	7	14
Obtained:	11	3	

four times, but only the higher or highest seed-set is shown in the table. The largest number of seeds obtained was considered to measure most accurately the true potentialities of a combination, any lower number probably resulting from poor pollination or from damage during crossing rather than from reduced compatibility. In every combination, the same type of results was obtained from the duplicates which generally were made by different persons at intervals ranging up to seven weeks. Although there was usually some variation between the duplicates in the exact number of seeds, there was generally no question as to whether a particular cross was compatible or incompatible. The average of the higher seed set in these compatible combinations was 44.9 per 10 flowers crossed, whereas the average obtained from the 114 incompatible crosses and selfs that were made, including duplicates, was 0.26 seed. It will be shown below that in a sample of these seeds from incompatible crosses approximately half resulted from contamination, so that the ratio between compatible and incompatible crosses in average seed-set is really twice as large as these numbers indicate. A similar difference between compatible and incompatible crosses in average seed-set was found among the F_2 matings (Tables 2, 3, 4, and 5).

These compatibility relationships seem to be explained best by the diploid personate type of multiple oppositional factors. This hypothesis was first presented with substantiating data by East and Mangelsdorf (3), using *Nicotiana*, and has since been applied to several other species. According to the theory, if a pollen grain carries the same allelomorph as one of those in the pistil, the resulting pollen tube fails to grow far enough to allow fertilization. On the other hand, if a pollen grain bears an allelomorph different from either of those in the pistil, pollen-tube growth is normal and fertilization is brought about. Incompatibility would be expected only in crosses between plants of the same genotype. Compatibility would result in crosses between plants differing in one or both factors, the progeny consisting respectively of two or four genotypes. The latter alternative appears to have been the condition shown in Table 1:

$$\begin{array}{ll} & \quad\;\; \text{I} \qquad\;\; \text{II} \\ \text{P} & \quad S_1S_2 \times S_3S_4 \\ & \qquad\qquad \downarrow \\ & \text{III} \qquad \text{IV} \qquad \text{V} \qquad \text{VI} \\ \text{F}_1 & S_1S_3 + S_2S_3 + S_1S_4 + S_2S_4 \end{array}$$

Since all four genotypes are different from those of the parents, all backcrosses should be reciprocally compatible (Table 1).

The four progeny genotypes, together with those of the two parents, constitute the six possible paired combinations of the four allelomorphs brought together from the two parents. On this interpretation can be based a progeny test (a) to check the applicability of the theory in predicting F_2 results and (b) to establish a certain genotype for each parental and F_1 group. The test consisted of crossing one F_1 group as a female with each of the other three groups. From one of these crosses, the F_2 should consist of equal numbers

TABLE 4.—*Number of seeds set per 10 flowers when F_2 plants from cross 1-III × 1-VI (1-7 × 1-6) were backcrossed to P and F_1 groups.*

Genotype	Plant No.		1-I (S_1S_2)	1-II (S_3S_4)	1-III (S_1S_3)	1-IV (S_2S_3)	1-V (S_1S_4)	1-VI (S_2S_4)	Average of compatible crosses
1-I (S_1S_2)	1-36	♀	0	34	30	27	41	15	29.4
		♂	0	—	—	—	—	—	
	1-37	♀	0	36	38	35	34	32	35.0
		♂	0	—	—	—	—	—	
	1-39	♀	0	24	13	0*	29	30	26.2
		♂	0	—	—	—	—	—	
1-II (S_3S_4)	1-40	♀	42	0	43	33	39	41	39.6
		♂	—	0	—	—	—	—	
	1-43	♀	37	0	40	27	30	31	33.0
		♂	—	2	—	—	—	—	
1-IV (S_2S_3)	1-44	♀	34	30	23	0	31	20	27.6
		♂	—	—	—	0	—	—	
1-V (S_1S_4)	1-38	♀	51	58	52	46	15†	53	52.0
		♂	55	25	43	51	0	39	
	1-41	♀	21	32	23	31	0	30	27.4
		♂	—	—	—	—	0	—	
	1-42	♀	39	33	27	35	0	11	29.0
		♂	—	—	—	—	0	—	
	1-45	♀	55	34	35	33	0	50	41.4
		♂	—	—	—	—	0	—	
	1-97	♀	24	22	33	27	0	—	26.5
		♂	39	0*	39	50	0	30	
	1-98	♀	—	—	21	32	0	—	26.5
		♂	46	10*	40	49	0	32	
Average of compatible crosses			46.7	25.0	40.7	50.0	—	33.7	34.8

*Cross was recorded compatible by reflection of pedicels on third day after pollination. This abnormally low seed set was omitted from average for plant.

†Cross was recorded as incompatible by no reflection of pedicels on third day after pollination. All 15 seeds were badly shrunken.

	1-I	1-II	1-IV	1-V	
Expected:	3	3	3	3	12
Obtained:	3	2	1	6	

of the group used as male and the group of the original female parent. From a second cross, the F_2 should consist of equal numbers of the group used as male and the group of the original male parent. And from the third cross, the F_2 should consist of equal numbers of the two F_1 groups not involved in this cross and the groups of both original parents. Following the designation used above, the results should be as follows:

$$\begin{array}{ccccc} \text{III} & & \text{IV} & & \text{I} & & \text{IV} \\ S_1S_3 & \times & S_2S_3 & \longrightarrow & S_1S_2 & + & S_2S_3 \end{array}$$

$$\begin{array}{ccccc} \text{III} & & \text{V} & & \text{V} & & \text{II} \\ S_1S_3 & \times & S_1S_4 & \longrightarrow & S_1S_4 & + & S_3S_4 \end{array}$$

$$\begin{array}{ccccccccccc} \text{III} & & \text{VI} & & \text{I} & & \text{V} & & \text{IV} & & \text{II} \\ S_1S_3 & \times & S_2S_4 & \longrightarrow & S_1S_2 & + & S_1S_4 & + & S_2S_3 & + & S_3S_4 \end{array}$$

In order to assign genotypes to the six groups, the four genes in the two original parents must be designated somehow and one of these genes from each parent must be arbitrarily assigned to one of the F_1 groups. The genotypes of the other three F_1 groups are then defined on the basis of progeny obtained when crossed with this one group. For example, following the designation shown above, if the group used as female for the three F_1 intercrosses is called III (S_1S_3), group IV (S_2S_3) is defined as the one which yields groups I and IV when crossed with III and which differs from III in the gene obtained from the original female parent (S_1S_2). Group V (S_1S_4) is defined as the one which yields groups II and V when crossed with III and which differs from III in the gene obtained from the original male parent (S_3S_4). Group VI (S_2S_4) is defined as the one which yields groups I, II, IV, and V when crossed with III and which differs from III in both genes.

When 39 F_2 plants from the three F_1 intercrosses were tested by backcrossing to representative plants from the two parental and four F_1 groups, only the expected groups were obtained (Tables 2, 3, and 4). Not all possible reciprocal combinations were made, but there were enough crosses with every plant to be certain of its genotype. The most critical crosses in every case involved (a) the reciprocal matings with the group with which a plant failed in order to check for possible homozygous genotypes and (b) matings with the other group or groups expected in that progeny in order to check for any unexpected failures due to disease or other environmental influences. The fact that only expected groups were obtained from all three crosses appears to prove the validity of the diploid personate theory as an explanation of cross-incompatibility in these plants of white clover. A comparison of expected and obtained, as given below the tables, indicates satisfactory agreement.

A material aid in carrying through the work was the fact that a pollination on to any plant could be predicted as compatible or incompatible by the behavior of the flowers subsequent to pollination. Within 20 to 24 hours after pollination the first differences could be observed. Following compatible crosses the standards and wings folded tightly around the keels, while they stayed unchanged after incompatible crosses. An even more distinct difference was seen in the degree of pedicel reflection 60 to 72 hours after pollination. After an incompatible cross, the pedicels stayed in approximately the same position as at pollination and there was no discoloration of the petals (Fig. 1). After a compatible cross, the pedicels became completely reflexed and the petals began to wither and turn brown

TABLE 5.—*Number of seeds per 10 flowers when homozygous plants were backcrossed to P and F_1 groups.*

Genotype	Plant No.	Parental group	Origin*		1–I (S_1S_2)	1–II (S_3S_4)	1–III (S_1S_3)	1–IV (S_2S_3)	1–V (S_1S_4)	1–VI (S_2S_4)	Average of compatible crosses
	1–46	1–III	A	♀	48	40	40	54	44	47	45.5
				♂	1	50	0	48	0	51	
	1–47	1–III	A	♀	38	22	44	35	36	34	34.8
				♂	1	6†	1	51	0	40	
S_1S_1	1–58	1–V	A	♀	—	—	—	—	44	—	44.0
				♂	0	37	1	53	1	51	
	1–61‡	1–V	A	♀	—	—	—	—	25	—	25.0
				♂	0	0†	0	0†	1	2†	
	1–84	1–V	B	♀	—	—	—	—	57	—	57.0
				♂	0	(45)	0	51	0	48	
S_2S_2	1–52	1–IV	A	♀	13	12	16	15	15	12	13.8
				♂	0	(36)	37	2	32	1	

	1–49	1–III	A	♀	37	33	26	28	22	5†	29.2
				♂	8†	0	0	0	37	17	
	1–51	1–IV	A	♀	28	0†	33	0†	29	4†	30.0
				♂	50	10	5	5	40	48	
S_3S_3	1–67	1–III	B	♀	44	33	38	38	33	42	38.0
				♂	44	0	0	2	36	52	
	1–73	1–IV	C	♀	—	—	—	26	—	—	26.0
				♂	22	0	0	1	39	41	
	1–77	1–IV	C	♀	—	—	—	40	—	—	40.0
				♂	54	0	0	0	49	32	
S_4S_4	2–77	2–IV	B	♀	—	—	—	—	—	—	
				♂	52	0	38	52	0	1	
Average of compatible crosses					44.4	42.0	37.5	51.0	38.8	42.2	37.1

*A = Incompatible cross in greenhouse; B = Self-pollination under bag in field; C = Incompatible cross under bee cage in field.
†Cross was recorded compatible by reflection of pedicels on third day after pollination. This abnormally low seed set was omitted from average for plant.
‡Plant was effectively male sterile. The anthers were very hard and did not dehisce when the flowers were tripped. The pollen was poor after it was crushed out of the anthers.

(Fig. 2). The head shown in Fig. 1 yielded no seed, while that shown in Fig. 2 yielded 41 seeds (the duplicate of this cross, listed in Table 1, yielded 42).

When part of the flowers on a head were pollinated with compatible pollen and the rest with incompatible pollen for controlled cytological studies of pollen-tube growth, these differences in withering of petals and reflexing of pedicels were just as evident. Several days after pollination the flowers used in incompatible crosses slowly withered and the pedicels bent over, but even then the heads did not appear the same as those in compatible crosses, since the latter soon became fleshy throughout as the pods developed, while the former dried up and only infrequently ripened any seeds. A few crosses yielded no seed after they had been predicted as compatible, but in every case mechanical injury or disease, especially virus, had been recorded, which probably explained the failure. Most cases of reduced seed production were correlated with a note that not all of the flowers had reflexed, probably due to improper pollination. Since this observation on pedicel reflections appeared to be reliable, only a few of the crosses with the F_2 plants were made in duplicate. In fact, the reaction was so distinct with the plants tested for homozygosity that some of them were considered heterozygous and not crossed further, solely on the basis of these notes, a procedure which proved justified when the seed yield was obtained.

A few seeds were obtained from the incompatible crosses and self-pollinations made in the greenhouse on the F_1 plants. Similarly, a few were obtained in the field from self-pollinations under bag and from incompatible crosses under bee cages. According to the personate theory, there is a 1:1 chance of these plants being homozygous, as indicated below:

$$S_1S_3 \text{ Selfed}$$
$$\downarrow$$
$$S_1S_1 + 2\ S_1S_3 + S_3S_3$$

Homozygous plants should be compatible as females with all six groups, but as males they should be incompatible with all groups possessing the gene for which they are homozygous, as follows:

$$S_1S_1 \times S_1S_2 \longrightarrow S_1S_2$$
$$S_1S_2 \times S_1S_1 \longrightarrow 0$$

The four homozygous genotypes can be distinguished by the groups with which they fail to set seed, as follows: S_1S_1—fails as male with I, III, and V. S_2S_2—fails as male with I, IV, and VI. S_3S_3—fails as male with II, III, and IV. S_4S_4—fails as male with II, V, and VI.

With all homozygous plants obtained, the reactions were as expected (Table 5). Only three of the four possible homozygous genotypes were found in this series, but the fourth has been secured from another series of unrelated plants. When 37 plants were tested in this way, 11 were homozygous, 7 heterozygous, and 19 contami-

nants (Table 6). The contaminant plants had other genotypes than those expected on the basis of the groups from which they arose and probably resulted from accidental cross-pollination. Apparently considerable error was possible in the pollination technic when making incompatible crosses or selfs, but the fact that there were no contaminants in either the F_1 or F_2 from compatible crosses indicates that there was much less chance for error when making these. As pointed out above, another conclusion drawn from the presence of only 18 legitimate offspring among the 37 plants is that their parents must have been about half as self-compatible as they were first thought to be, which effectively doubles the ratio of average seed set between compatible and incompatible crosses.

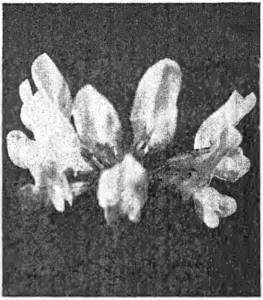

FIG. 1.—Flowers 72 hours after incompatible cross 1–7 × 1–9. ×2.

In order to test whether certain combinations which were compatible or incompatible in the greenhouse would give the same results with bee pollination in the field, cages were set up over two or three plants. (The technic will be described in another publication). From two compatible crosses with this series of plants, about 80 and 90 times as much seed, respectively, was obtained as from the incompatible cross. These differences are not of quite the same magnitude as those obtained in the greenhouse with hand pollination, but they are certainly of practical significance.

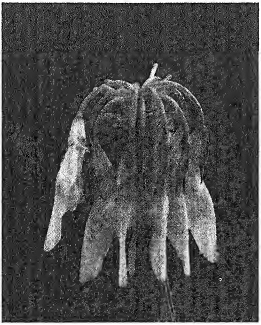

FIG. 2.—Flowers 72 hours after compatible cross 1–7 × 1–12, made at the same time and on the same plant as the head shown in Fig. 1. ×2.

In another series of plants involving one highly pseudo-self-compatible parent, the cross-incompatibilities appear to be interpretable on the same diploid personate theory (1). All evidence from crossing both related and unrelated plants indicates that there must be a large number of multiple allelomorphs causing incompatibility in white clover.

The cytological basis for these incompatibilities has been found to be poor pollen germination and pollen-tube growth both on

TABLE 6.—*Summary of homozygous test.*

Parental group	Homozygous	Heterozygous	Contaminants	Total
1–III	4	2	7	13
1–IV	4	4	2	10
1–V	3	1	9	13
1–VI	—	—	1	1
Total..........	11	7	19	37

	Homozygous	Heterozygous	
Expected:	9	9	18
Obtained:	11	7	

the stigma and in the style. Since this reaction takes place within a few hours after pollination, practically no tubes reach the ovary. The difference in behavior between compatible and incompatible pollen is so distinct that by examination of smeared stigmas, it is possible to distinguish pollinations in which the plants differ in two, one, or no factors. These results will be reported in detail later.

Another genetic observation in this study concerns the average number of seeds set in compatible crosses. These values are probably most accurate in Table 1 where the most crosses per plant are recorded and where nearly all crosses were made at least in duplicate. The seed-set on the original female parent, 1–1, ranged from 39 to 51 and averaged 45.7, while that on the male parent, 1–2, ranged from 46 to 54 and averaged 50.3. The F_1 varied from an average of 35.3 on plant 1–12 to 49.6 on plant 1–14. Although this entire range was not represented among the F_1 plants selected as parents of the F_2, the averages obtained among the different F_2 families were correlated with those of their F_1 parents. Apparently this character is inherited and may be conditioned by several genes, for which the original parents were probably heterozygous. The plant with the best seed-set of all those tested was from another series. Although used in only five crosses, an average seed-set of 62.0 was obtained. Plant 1–52 (Table 5) yielded the lowest average seed-set of 13.8. A cytological examination of pistils from representative plants in this range, both before fertilization and during embryo development, indicated that the principal factor influencing this difference was the number of ovules borne by the different plants. By removing all but 10 flowers from a head, the extra food available was probably a factor in causing ovules which otherwise might have aborted to develop into good seeds. Consequently, the number of seeds set per flower in these controlled crosses is a measure of the number of ovules produced. Some abortion takes place in the field on entire heads, where an average seed-set of over two per pod is found only occasionally even with the highest producing open-pollinated heads. Despite these differences in ovule abortion between greenhouse and field, a significant correlation ($r=.875$, $P<.01$) was found between the average seed-set per 10 flowers in the greenhouse and the average seed-set per head under bee cages in the field, based on the 25 best heads harvested from each of seven plants used in compatible crosses. Apparently these differences in number of ovules produced may be

of practical significance and should be considered in a breeding program.

DISCUSSION

A difference in seed yield between compatible and incompatible crosses has been the most common method used to distinguish these reactions, but with some species an arbitrary class limit has been used to separate the two kinds of crosses and in some cases the classes have overlapped. In white clover, no such difficulties occur, the seed yield being an excellent measure of compatibility. The two classes are very distinct and practically no overlapping occurs. In several groups of crosses the average yield from the compatible crosses was hundreds of times as great as from the incompatibles. These differences were dependent on the precision with which emasculation and pollination were done, but the technics were not difficult to learn or to execute.

Emerson (4) reported that direct tests of pollen-tube development as seen in smeared stigmas of *Oenothera organensis* were more reliable in determining cross-incompatibilities than failures in seed production. A similar technic for stigma smears has proved satisfactory for white clover. This species is distinctive in the speed and finality with which this reaction takes place on the stigma. By this procedure it can also be determined whether two compatible plants differ in one or both factors simply by observation rather than by a progeny test.

There was found, however, in white clover a much simpler and more reliable method for predicting seed yields than the direct tests of pollen-tube development. The degree of pedicel reflection on the third day after pollination provided a measure of compatibility which worked reliably with every plant and which was practically uninfluenced by diseases or other environmental factors. These observations were used instead of making duplicate crosses in order to check on reduced seed production or unexpected seed yields.

Incompatibility in white clover has been interpreted according to the diploid personate theory, but the plants used in this study were tetraploids. Root tips from representative F_1 plants were all found to have the regular somatic number of 32. When meiosis was studied in the microsporocytes of 11 plants of white clover (2), including the original female parent of the plants used in this investigation, it was found that the 32 chromosomes regularly associated as 16 bivalents. It was concluded that white clover is probably an amphidiploid, rather than an autotetraploid and that disomic segregation should be expected. Since a disomic segregation has been obtained for the multiple allelomorphs conditioning cross-incompatibility, it may be inferred that these allelomorphs are present in only one of the two genomes found in white clover.

SUMMARY

When the plants used in this investigation were self-pollinated in several ways and at different times, the seed-set was so low that all were considered practically self-incompatible.

Thirteen F_1 plants consisted of four intra-sterile, inter-fertile groups of five, four, three, and one plant, respectively, and all were reciprocally compatible with both parents. Using 10 flowers in each mating, compatible crosses averaged 44.9 seeds and incompatible 0.26.

These results are best explained by the diploid personate type of multiple oppositional allelomorphs (3), where the parents differed in both factors.

To check further the applicability of this theory to white clover and to establish a certain genotype for each parental and F_1 group, 39 F_2 plants from three F_1 intercrosses were tested by backcrossing to the two parental and four F_1 groups, and only the expected groups were obtained.

When 37 plants from incompatible crosses and selfs were tested by backcrossing to the two parental and four F_1 groups, 11 were homozygous, 7 heterozygous, and 19 contaminants. Three of the four possible homozygous genotypes were among these 11, and the fourth was obtained from an unrelated series of plants.

Within 20 to 72 hours after pollination, crosses on to any plant could be predicted as compatible or incompatible by the withering of the petals and the reflexing of the pedicels.

The number of seeds set per flower in compatible crosses is a measure of the number of ovules produced, and this character appeared to be inherited. Plants have averaged from 13.8 to 62.0 seeds per 10 flowers, and these differences in seed set in the greenhouse were significantly correlated in the seven plants tested ($r = .875$, $P < .01$) with the seed set under bee cages in the field.

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YIELDS OF KOREAN LESPEDEZA AS AFFECTED BY DODDER[1]

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IN MANY sections where the annual lespedezas are grown, common dodder (*Cuscuta pentagona* Engel.) is found as a parasite on the lespedeza. Dodder is usually considered a noxious weed, and in spite of control measures that have been attempted, apparently is becoming more widely distributed from year to year. Questions often arise as to the effect of dodder on the hay and seed yields of lespedeza and on the relative feeding value of dodder-infested hay. It is desirable, therefore, that more information on the subject be made available.

During the season of 1939, square yard areas of adjacent infested and non-infested Korean lespedeza were harvested at Statesville, N. C. As the dodder was located in scattered spots from 10 to 30 feet in diameter, it was possible to obtain infested and non-infested paired samples from areas only a few feet apart. The hay samples were harvested on September 9. The dodder was separated from the lespedeza and the samples of lespedeza dried in the shade. It was necessary to dry the dodder in an oven at 80° C to prevent additional growth and spoilage from the high moisture content. Oven-dry weights were obtained after the samples had reached a constant weight at 100° C.

The yields of hay are given in Table 1. The average yield of dodder-free lespedeza was 3,670 pounds and of the dodder-infested plots 3,677 pounds per acre. The amount of pure lespedeza was about 28% less on the dodder-infested plots than on the dodder-free plots, but the growth of dodder very nearly equaled the amount of the reduction of the lespedeza growth so that the total hay yields of both dodder-infested and dodder-free lespedeza were similar.

TABLE 1.—*Hay yields in pounds per acre of Korean lespedeza and dodder on a 12% moisture basis.*

Sample No.	Lespedeza grown with dodder			Lespedeza grown dodder free
	Lespedeza	Dodder	Lespedeza and dodder	
1	2,750	653	3,403	3,395
2	3,061	1,307	4,368	3,868
3	2,389	1,051	3,440	3,516
4	2,898	819	3,717	3,416
5	2,285	1,147	3,432	3,887
6	2,474	1,226	3,700	3,941
Average	2,643	1,034	3,677	3,670

[1]Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, the North Carolina Department of Agriculture, and the North Carolina Agricultural Experiment Station. Received for publication October 14, 1940.

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Dodder-infested hay is readily eaten by livestock. As a measure of feeding value, chemical analyses of the samples were obtained and are given in Table 2 with grade determinations and leafiness. Many of the leaves on the dodder-infested lespedeza had yellowed and some had been lost before harvest, which accounts for the difference in grade between the two hays. These same factors probably also account for the lower protein and nitrogen-free extract and higher crude fiber content of the dodder-infested lespedeza as compared to that grown free of dodder.

TABLE 2.—*Chemical analyses of Korean lespedeza and dodder on a 12% moisture basis.**

Nature of sample	Class and grade	Protein %	Crude fat %	Crude fiber %	Ash %	Nitrogen-free extract %
1. Lespedeza grown dodder-free	U. S. No. 1, extra leafy, extra green lespedeza, 60% leaves	14.70	1.23	29.73	4.41	37.93
2. Lespedeza grown with dodder	U. S. sample grade, green, extra leafy, lespedeza, foreign material, 28.12% dodder	12.35†	1.37†	28.26†	4.53†	41.49†
3. Lespedeza with dodder removed‡	U. S. No. 1, extra leafy lespedeza, 55% leaves	12.01	1.29	33.40	4.59	36.71
4. Dodder removed from the lespedeza of sample 3		13.23	1.57	15.08	4.39	53.73

*Analyses and grade determinations by Grain and Seed Division, Agricultural Marketing Service, U. S. Dept. of Agriculture.
†Calculated from analyses of the dodder and lespedeza made separately, items 3 and 4.
‡Pure lespedeza from which dodder of sample 4 had previously been separated.

The dodder contained slightly more protein than the lespedeza upon which it grew but less than the lespedeza grown dodder-free. The crude fiber content of the dodder was about half that of the lespedeza. Combining the analyses of the lespedeza and the dodder that grew on it, we have a hay slightly lower in protein and crude fiber and higher in fat, ash, and nitrogen-free extract than the hay grown dodder-free.

Square yard samples from the same field were harvested on October 23, 1939, for seed yield determinations. Ten samples were obtained from the dodder-infested areas and a like number in the dodder-free lespedeza. The seed yields are given in Table 3. The average seed yield of the lespedeza grown dodder-free was 712 pounds while the infested lespedeza seed yield was 70% less. The dodder produced an average of 390 pounds of seed per acre.

TABLE 3.—*Seed yields in pounds per acre of Korean lespedeza and dodder computed from square yard plots.*

Sample No.	Lespedeza grown dodder-free	Lespedeza and dodder grown together		
		Lespedeza	Dodder	Total of lespedeza and dodder
1	736	133	487	620
2	759	260	297	557
3	695	273	300	573
4	712	284	380	664
5	796	85	450	535
6	842	247	460	707
7	633	215	377	592
8	617	199	284	483
9	653	170	471	641
10	678	251	394	645
Average	712	212	390	602

SUMMARY

1. Under the conditions of an experiment conducted during 1939 at Statesville, North Carolina, hay made from dodder-infested lespedeza contained 72% lespedeza and 28% dodder.

2. The total hay yield from the dodder-infested plots was similar to the yield from the dodder-free plots.

3. There was some loss of leaves and considerable loss in color of the dodder-infested lespedeza.

4. The protein content of the dodder was slightly greater than that of the lespedeza on which it was grown but was somewhat less than that of lespedeza grown free of dodder.

5. Dodder contained only about half the amount of crude fiber found in the lespedeza.

6. Seed yields of the Korean lespedeza were reduced from 712 to 212 pounds per acre by the dodder.

NOTES

STORING ALFALFA SEEDLINGS[1]

A RECENT experiment has shown that alfalfa seedlings may be stored for at least five months without material loss of plants. Storing seedlings for such a period makes it possible to grow two crops in the same greenhouse space through the winter for spring transplanting.

The experiment was conducted by placing a definite number of plants in each of a series of commercial cold storage rooms at temperatures ranging from 42° F to as low as 18° F. The plants used were from a field seeded the previous fall with certified Kansas Common seed. The seedling roots when dug in June averaged about 8 mm in diameter. Before storing, the roots were washed, the tips cut off 8 inches below the crown, and the tops trimmed, leaving very little green material. These plants were hardened slightly by first placing them in a temperature of 50° F for 3 days and then in lower temperatures as reported in Table 1.

TABLE 1.—*Percentage survival of alfalfa plants after a period in cold storage.*

Length of storage period, months	Percentage survival at a temperature of		
	40° to 42° F	32° to 34° F	14° to 18° F
1	100	100	0
2	100	100	0
3	100	100	0
4	80	96	0
5	92	96	0

Every 30 days for 5 months 50 plants were removed from each room and planted in the greenhouse to determine the survival. They were left in the bed long enough to be certain of their survival.

Actual experience in 1940 corroborated the results of the experiment. During the winter of 1939–40, 25,000 seedlings were grown in the greenhouse. Half of these, from seed sown in September, were placed in a cold storage room in January at 34° to 38° F without hardening, and transplanted to the field in May. A similar number, from seed sown in the greenhouse in January, was transplanted directly from the greenhouse beds to the field in May. Very few plants were lost from either group; no more than would normally be expected in transplanting.

The response of the two groups after transplanting was striking in that the stored plants started growth quicker and were in bloom four to five days earlier than those transplanted directly from the greenhouse.—C. O. GRANDFIELD, *Kansas State College, Manhattan, Kansas.*

[1]Joint contribution from the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, and the Agronomy Department, Kansas Agricultural Experiment Station, Manhattan, Kansas. Contribution No. 311 Department of Agronomy.

A SUGAR BEET SAMPLE WASHER

A NEW type of sugar beet sample washer has been developed at the Michigan State Experiment Station. This washer (Fig. 1) consists essentially of a tank, approximately 36 by 34 inches and 30 inches deep, and a rotating skeleton drum containing the cages or baskets in which the samples of roots are placed. The skeleton drum, mounted

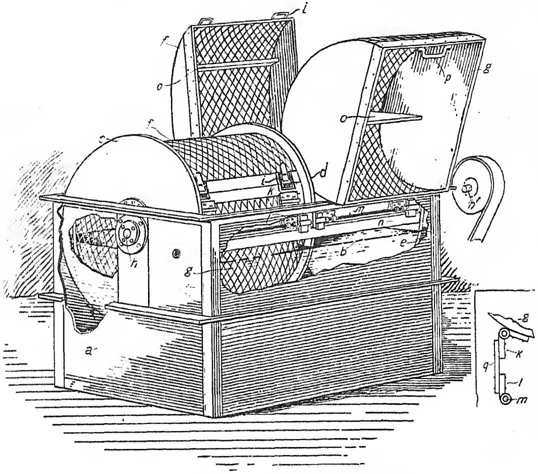

FIG. 1.—New type sugar beet sample washer.

on short shafts at either end, consists of parallel disks, approximately 30 inches in diameter, with three cross bars attached to them at the circumference. One of these cross bars is shown (n); the others are at the succeeding 90 degree points on the circumference so that a full 180 degrees is left without any cross bar.

A special feature of this machine is the construction of the cages. Each consists of a top and a bottom section. When the rotating drum is stopped at the proper point, the top section, hinged to the back cross bar, can be turned back out of the way and the bottom section, double hinged (see inset) to the front cross bar, can be turned up and forward to a position where the washed roots will fall out.

With this machine the roots are washed in water that is stirred gently by the baffles on the inside of the cages (the drum and cages revolve from 15 to 20 times a minute), and the thoroughness of the washing is determined by the length of time the sample remains in

the machine. Since the beet roots are in water all the time they are being washed, root breakage is reduced to a minimum.

Further information concerning the construction of this machine will be furnished anyone interested.—J. G. LILL, *Division of Sugar Plant Investigations, U. S. Dept. of Agriculture, East Lansing, Michigan.*

BURIED RED RICE SEED[1]

WE HAVE previously[2] reported on the vitality of two varieties of commonly cultivated rice and of five lots of red rice after being buried in the soil for seven years. Both the Supreme Blue Rose rice and the Caloro rice failed to survive the second winter in the ground. After the seventh winter, practically all of the red rices were dead at Biggs, Calif., and Beaumont, Tex. At Stuttgart, Ark., both the Southern Blackhull rice and the two southern red rices were still alive. In the spring of 1940, the last remaining lot of seed was taken up at Stuttgart and gave the germination shown in Table 1.

TABLE 1.—*Vitality of red rice after being buried in the soil at Stuttgart, Ark., for 10 years.*

Kind	Percentage germination	
	Irrigated soil	Non-irrigated soil
Southern red	9.0	0.0
Southern red	21.0	0.0
Southern Blackhull	28.0	0.0
Italian red	0.5	0.5

It is interesting to note the persistence in the irrigated plot as compared with the non-irrigated plot.—W. L. GOSS AND EDGAR BROWN, *U. S. Dept. of Agriculture.*

[1]Contribution from the Grain and Seed Division, Agricultural Marketing Service, and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

[2]Jour. Amer. Soc. Agron., 31:633–637. 1939.

BOOK REVIEWS

HANDBOOK OF MATHEMATICAL TABLES AND FORMULAS

By Richard S. Burington. Sandusky, Ohio: Handbook Publishers, Inc. Ed. 2. VI+275 pages. Illus. 1940.

THE contents of this volume, except for slight additions, forms an appendix to Lange's Handbook of Chemistry. An examination of either the first or third edition of the latter will acquaint the worker with the contents of the mathematical handbook. The additions consist of over 100 equations in the table of Integrals, tables of Logarithms of Factorial *n*, Factorials and Their Reciprocals, and Binomial Coefficients. The table of Squares, Cubes, etc., has been increased by the addition of values for Square Root on 10*n*, Cube Root of 10*n*, and Cube Root of 100*n*.

The first part of the volume (95 pages) consists of "formulas and theorems from elementary mathematics" which include algebra, geometry, trigonometry, analytical geometry, differential and integral calculus, and vector analysis. Many research workers would consider part of the discussion and many of the formulas as being more than elementary. The second part (173 pages) consists of 30 tables such as four, five, and seven place common logarithms of numbers, natural logs of numbers, natural trigonometric functions and logarithms of the same, exponential and hyperbolic functions, tables of radian measure (4), circular measure (2), gamma function, factorials, probability functions, factors for probable error, interest, discount, annuity, American mortality, etc. An index completes the volume.

This work, while giving numerous, extensive tables of use to engineers, physists, chemists, and other scientists, omits many tables of value to the statistician and biometricians (probably because of copyright restrictions) so should be considered as supplementary to such works as Pearson's Tables and those of other statistical workers. Neither is the table of Squares, Cubes, etc., as extensive as the well-known Barlow's Tables. Even with these omissions, the author has packed an immense amount of mathematics in a small volume. In fact the very brevity of most mathematical handbooks is a serious defect in the eyes of many workers including research scientists. Mathematicians can scarcely realize how "rusty in math" most workers become within a few years after leaving college. Illustrative examples worked out with sufficient detail to show how the complicated formulas of higher mathematics should be computed and how some of the less common tables should be used would be greatly appreciated by many workers. More mensuration formulas would also be welcomed.

The book is well written, and the paper, printing, and binding are excellent. Placing the mathematical part in a separate volume is an advantage to those not interested especially in the Chemical Handbook since it makes a less expensive volume and one more convenient for computing. (F. Z. H.)

AN AGRICULTURAL TESTAMENT

By Sir Albert Howard. London: Oxford University Press. 253 pages, illus. 1940.

THE major thesis of the author of this book is that the loss in soil fertility resulting from the vast increase in crop and animal production in order to feed the growing population of the world, has led to disastrous consequences. The result has been a general unbalancing of farming practices, an increase in plant and animal diseases, and finally the actual removal of soil by erosion. These losses can be overcome only by proper addition of humus or humus-forming materials to the soil and by the utilization of the activities of mycorrhiza fungi, which form the living bridge between soil humus and plant growth.

Sir Howard has written a most stimulating book and, although some readers may not fully agree with his general thesis, they will not lay this book aside until they have read it through. (S.A.W.)

STATISTICAL METHODS

By George W. Snedecor. Ames, Ia.: The Iowa State College Press. Ed. 3. XIII + 422 pages, illus. 1940. $3.75.

QUOTING the publisher, this "third edition was published under the imprint of the Iowa State College Press, whereas former editions were published by the Collegiate Press, Inc. This amounts principally to a change in name (of publisher), but it also brings to the book and future books published under the new imprint the approval of an editorial board drawn from the staff of Iowa State College".

With the exception of corrections of errors and additions mentioned below, the text of the second edition is practically unchanged, although section 10.16 has been largely re-written. The reader is referred to previous reviews in this JOURNAL, as follows: Original edition, Vol. 29, page 1033; second edition, Vol. 30, page 1045.

The total additions embrace 34 pages and, in addition to the entire last chapter, include the following sections: (1) Analysis of variance in regression; and (2) transformation of data for tests of significance in which square root, angle, and logarithmic transformations are discussed. The complete table of angle-arcsine $\sqrt{\text{percentage}}$ by Bliss is also included which is fortunate since many students might not have access to the Russian journal in which this table appeared originally.

The largest addition is Chapter 17 (29 pages) entitled "Design and Analysis of Samplings". Here the author points out the pitfalls to be avoided in sampling and gives numerous worked examples of analysis of such data. The headings of this chapter are population, sampling from a homogeneous population, size of sample, sampling from small populations, sampling from two or more homogeneous populations, analysis of data from two or more populations, structure of sampling investigations, and the effectiveness of subdivision. All these additions should be welcomed by workers in agriculture and biology for whom this volume is especially designed. (F. Z. H.)

SOIL PHYSICS

By L. D. Baver. New York: John Wiley & Sons. IX+370 pages, illus. 1940. $4.

THERE has been rapidly developing in recent years an increasing tendency to differentiate more and more clearly the various phases of the field of agronomy. The subject matter dealing with the physical properties of soils has generally been covered more or less completely in text books of agronomy or soils. Ever since the classic work of King and later Hilgard the importance of the physical aspects of soils has been recognized. In later years as the subject developed soil workers and teachers have felt the need of something really comprehensive dealing with these physical properties. A great deal of research has been done in the field but, as the author of the present volume points out, this material is scattered widely with a large part of it in foreign publications. This is one reason why Keen's "The Physical Properties of the Soil", published in 1931, was well received.

"Soil Physics" has been prepared, according to the author, to meet these needs, especially of the teacher of soils as the material is stated to be of graduate and advanced undergraduate grade. The author is one who has apparently felt this need in his own teaching work and furthermore is well qualified both in teaching experience and in soil research.

The book covers mechanical composition, soil colloids, soil consistency and structure, water, air, heat, and physical properties as related to tillage, runoff, and erosion. The more fundamental references are given at the chapter ends and the book has an author and subject index. It should be warmly welcomed by teachers of the subject of soils and by research workers in the same field. (R. C. C.)

MINUTES OF THE THIRTY-THIRD ANNUAL MEETING OF THE AMERICAN SOCIETY OF AGRONOMY

THE thirty-third annual meeting of the Society was held in the Drake Hotel in Chicago, Illinois, December 4, 5, and 6. There were 667 registered at the meetings which were held jointly with the Soil Science Society of America.

The general meeting of the Society was held on Thursday morning, December 5, with President F. J. Alway presiding. Dr. E. J. Krauss of the University of Chicago gave a very interesting illustrated lecture on "Possible Use of Growth Substances in Agricultural Practice". This was followed by a paper entitled "Integrating Soils and Crops Research" by R. M. Salter, Director of the North Carolina Agricultural Experiment Station. Both papers were very well received by the members in attendance and will be published in the JOURNAL.

The annual dinner of the Society was held on Thursday evening. Following the dinner President F. J. Alway gave an address on "A Nutrient Element Slighted in Agricultural Research".

The Crops Section had one general session and nine subsectional meetings at which 51 papers were presented. In addition, there were two round table discussions.

The Soil Science Society of America had one general program and 13 sectional programs with a total of 74 papers.

A joint meeting of the Soils and Crops Sections was held on Wednesday afternoon at which time six papers were presented in a symposium on "Relation of Soil Types and Fertilizer Treatment to Quality and Composition of Crops".

"War and Agricultural Adjustment with Special Reference to Grassland Agriculture" was the subject for discussion on a joint program Friday afternoon.

The Auditing Committee appointed by President Alway consisted of Dr. F. B. Smith and Dr. L. A. Richards. The Nominating Committee consisted of President Alway, chairman, and Dr. W. H. Pierre, Dr. S. C. Salmon, Dr. W. B. Kemp, and Dr. F. C. Bauer.

FELLOWS ELECT

VICE President L. E. Kirk announced the Fellows Elect and presented the certificates at the annual dinner on the evening of December 5. The following were elected Fellows of the Society: Dr. L. F. Graber, Dr. P. C. Mangelsdorf, Dr. F. W. Parker, and H. R. Smalley. The citations of these Fellows will appear in a later number of the JOURNAL.

OFFICERS' REPORTS

REPORT OF THE EDITOR

ONCE more the time has come to take stock of another volume of the JOURNAL. Volume 32 for 1940 will not differ materially from the last few preceding volumes, at least with respect to number of pages, number of articles published, and so on. This has become a rather routine record, but here are the figures

for 1940: Papers published, 109; "Notes" published, 17; book reviews published, 13; papers now under review, 11; papers approved and awaiting publication, 12; papers returned for one reason or another, 17.

The JOURNAL is really in very good shape with respect to manuscripts. The January 1941 number is now in the hands of the printer and there are sufficient papers in sight for the February issue without drawing on manuscripts that will be forthcoming from this meeting. This means that publication in the JOURNAL may be reasonably expected within a three months' period after acceptance of a paper, and this is just a comfortable margin from the standpoint of the Editor.

Here is the usual procedure. A manuscript is received in our office on December 4, let us say. Generally, the day the manuscript arrives it is entered on our record and a post card acknowledging receipt is mailed to the author. At the same time the manuscript is transmitted either to the Associate Editor in Crops or the Associate Editor in Soils, depending upon the subject matter.

While there is a good deal of variation in the length of time that papers are in the hands of the reviewers, generally we have a report on the manuscript within two weeks, or for purposes of our illustration, we would expect to have a report on a paper received on December 4 about December 18. Almost invariably, the report from the reviewers will necessitate a letter to the author and generally will call for return of the manuscript itself for further attention. If you submit a manuscript to the JOURNAL and skip this step in the procedure, you may count yourself as among the favored few who tell their story so clearly the first time that even the reviewers can understand what it is all about.

But if you are one of the great majority of contributors to the JOURNAL, you will be given an opportunity to benefit from the suggestions offered by the editorial board, and almost invariably you will welcome this opportunity. In my experience of 12 years of editing the JOURNAL, I have only encountered one instance in which a contributor resented even the implication that his paper could be in the least improved and demanded that it be published as submitted or not at all. It has not yet been published in our JOURNAL.

We do not expect that you are going to agree in all respects with the criticisms offered by the reviewers, but from our past experience we know that 99.9 per cent of you are going to welcome the opportunity to preview the line of attack that may be leveled against your paper should it be published without regard to the critical comments offered by a fair-minded group of reviewers.

The paper is in your hands and the next move is up to you and perhaps you will be surprised to know that most of the delay in moving a manuscript along in the publication schedule is right at this point due to the difficulty of getting papers back from the author. Of course if your paper came back on December 19 or 20, you would be too busy with your Christmas shopping to do anything about it until after Christmas and perhaps you will go off to the A. A. A. S. meetings or some other interruptions will occur during the Christmas holidays so that it will be well along into January before you dig down through the accumulations on your desk and set to work to make such revisions of your manuscript in the light of the reviewers' comments as you may deem desirable.

At best you will not get your paper back to us until about the middle of January, long after the copy for the February number of the JOURNAL has had to go to the printer. And so the best that we can do with this theoretical paper which reached us on December 4 is to edit it for the March number of the JOURNAL, hence publication within three months after submission of a manuscript is about as early as one may reasonably expect under our present procedure.

This is the reason, too, why we need a "back log" of papers to insure a steady flow of manuscripts to the printer.

Order of publication in the JOURNAL is by priority, that is the papers appear in the order of their date of receipt in our office, insofar as circumstances will permit. Undue delay in acting on a manuscript by the reviewers or by the author will, of course, throw a paper out of line. For example, a paper now scheduled for the February number of the JOURNAL was actually received on July 8 but was returned to me by the author only a few days ago.

All of this is to say again that the JOURNAL is now in a position where it can render reasonably prompt service and we would welcome the opportunity to see just as many papers as you wish to send our way.

The inauguration at the last annual meeting of an Editorial Board comprising two Associate Editors and a corps of Consulting Editors has, in our estimation, proved to be one of the most constructive moves and certainly the most helpful action so far as the Editor is concerned, that has transpired for some time. The two groups of Consulting Editors, headed up by Dr. R. J. Garber for crops and Dr. Emil Truog for soils, have taken their responsibilities seriously and have rendered a truly important service to the Society and the JOURNAL. They and a number of others whom they have called upon from time to time to aid them in dealing with manuscripts of a highly specialized character are deserving of the gratitude of all of us for maintaining the high standards that we like to believe characterize the JOURNAL.

One thing more about manuscripts. One of the Associate Editors wrote to us last summer as follows: "I think we will have to try and do something in the way of educating some of our members in the matter of writing articles which are suitable for publication. If the authors would spend a little more time in studying their article and polishing it up, it would certainly help a lot in lessening the work of the reviewer and also in hastening the time of publication. . . . The reason it now takes such a long time to get the articles reviewed and finally approved is because of the unsatisfactory shape in which the articles are submitted." I am sure a great chorus of "Amens" to that statement would go up from editors of scientific journals in general.

We do not expect literary masterpieces; but it is a fact that much could be done in the way of better organization and in more accurate grammatical construction of papers coming to the JOURNAL. As an aid in this direction we are appending to this report a "Guide to Contributors to the JOURNAL". This will aid in the organization of a manuscript along the lines recognized as the style of the JOURNAL. This does not mean that our style is the one and only way of doing things, but it is recognition on the part of all, we assume, that there should be some consistent procedure in editorial details and general appearance of the JOURNAL. A little observation on the part of contributors of the printed pages of the JOURNAL and use of this "Guide" should go a long way toward meeting the needs expressed above.

During the year, we have entered into an agreement with a firm of advertising solicitors who, beginning January 1 next, will assume full responsibility for the advertising in the JOURNAL. This plan already shows promise of substantial gains in advertising revenue in 1941 and is recognition of the fact, of which we have long been aware, that personal contact with potential advertisers would accomplish much more than a letter-writing campaign to which of necessity we have been largely confined in the past. We have enjoyed a fairly good year in

the way of advertising and wish here to acknowledge our thanks to those advertisers who have patronized the JOURNAL during 1940.

For purposes of the record, we would report here the number of copies of the various agronomic publications entrusted to our care which have been shipped out since January 1. They are as follows: 7 sets of the PROCEEDINGS of the First International Society of Soil Science; 13 BULLETINS of the Soil Survey Association; 40 INDEXES to the JOURNAL; 1,892 back numbers of the JOURNAL; 132 volumes of PROCEEDINGS of the Soil Science Society; and 4 sets of the TRANSACTIONS of the Third Commission of the International Society of Soil Science.

We still need to be kept better informed on matters of general agronomic interest to be published under the heading of "News Items". Some of our correspondents are very regular; but for the most part such news items as we do gather together are come upon in a very haphazard manner. We suggest that all of you make "more news for the JOURNAL" one of your 1941 New Year's resolutions.

Once again in concluding another report and another volume of the JOURNAL we acknowledge the invaluable aid and cooperation of the Secretary. His patience and good nature must be unfailing, for I am sure we try them mightily throughout the year. The smooth functioning of his office is essential not only to the efficient conduct of the affairs of the Society, but to the maintenance and publication of the JOURNAL as well. That both are flourishing is concrete evidence of his efficiency.

Respectfully submitted,

J. D. LUCKETT, *Editor*.

REPORT OF THE SECRETARY

THE membership changes in the Society since the last annual report are briefly summarized as follows:

Membership last report		1,205
New members, 1940	127	
Reinstated members	67	
Total increase	194	
Dropped for non-payment of dues	187	
Resigned	18	
Died	6	
Mail returned unclaimed	12	
Total decrease	223	
Net decrease		29
Membership, October 31, 1940		1,176

The changes in number of subscribers are as follows:

Subscriptions, last report		687
New subscriptions, 1940	89	
Subscriptions dropped	182	
Net decrease		93
Subscriptions, October 31, 1940		594

The paid up membership and subscription lists by states and countries are as follows:

	Members	Subscriptions
Alabama	17	1
Arizona	12	5
Arkansas	16	4
California	49	14
Colorado	20	1
Connecticut	11	2
Delaware	4	1
District of Columbia	91	6
Florida	18	3
Georgia	20	6
Idaho	9	1
Illinois	56	13
Indiana	30	4
Iowa	42	4
Kansas	46	4
Kentucky	11	3
Louisiana	18	5
Maine	5	1
Maryland	15	4
Massachusetts	13	4
Michigan	23	5
Minnesota	32	5
Mississippi	12	3
Missouri	21	3
Montana	9	6
Nebraska	36	4
Nevada	3	1
New Hampshire	2	1
New Jersey	19	4
New Mexico	5	3
New York	44	15
North Carolina	20	6
North Dakota	12	1
Ohio	53	5
Oklahoma	13	5
Oregon	12	4
Pennsylvania	22	7
Rhode Island	7	0
South Carolina	19	2
South Dakota	8	1
Tennessee	14	3
Texas	52	14
Utah	15	6
Vermont	3	1
Virginia	26	3
Washington	24	4
West Virginia	10	1
Wisconsin	35	4
Wyoming	7	1
Alaska	1	1
Hawaii	6	12
Philippine Islands	1	2
Puerto Rico	4	3

	Members	Subscriptions
Africa	4	27
Argentina	10	15
Australia	1	28
Belgium	0	1
Brazil	1	9
British Guiana	0	1
British West Indies	1	1
Bulgaria	0	1
Canada	25	42
Ceylon	0	3
Chile	1	1
China	5	17
Colombia	0	2
Cuba	4	2
Denmark	2	1
Dutch East Indies	0	5
Egypt	0	3
England	2	15
Estonia	0	1
Fed. Malay States	0	5
Fiji	0	1
Finland	0	6
France	0	7
Germany	4	3
Greece	0	2
Holland	0	5
Honduras	0	2
India	4	25
Indochina	0	1
Ireland	0	1
Italy	1	7
Japan	2	82
Mauritius	0	1
Mesopotamia	0	1
Mexico	1	2
New Zealand	0	6
Norway	0	2
Palestine	2	0
Peru	0	3
Portugal	0	5
Roumania	0	1
Scotland	2	2
Siam	2	2
Spain	0	2
Sweden	0	3
Switzerland	1	1
Turkey	2	1
Uruguay	1	0
Russia	1	9
Venezuela	1	2
Wales	0	3
Total	1,153	590

The total membership shows 29 members less than were reported last year. This is explained by the larger number of members who were dropped for non-payment of dues. On July 1, all members who had not paid their 1940 dues or who had not indicated that they would pay later were dropped from the membership

rolls. As a result we have only 23 members on our rolls who have not paid 1940 dues. At the time of last year's report there were 179 members who were at least one year behind in payment of dues. Thus, although our total membership is lower than last year, we have 126 more paid up members than we had one year ago. This increase in members in good standing is in part the result of more prompt payment of dues and also the increased number of new members. The cooperation of the various state representatives, as well as other members of the Society, has made this possible.

The total number of subscribers is 93 less than last reported. The large decrease is principally due to the fewer number of subscribers in the U. S. S. R. Last year there were 95 Russian subscribers, whereas this year there are only 9, a decrease of 86. The number of paid up subscribers is only 8 less than last year. Under present conditions it seems doubtful if we can hope to increase the number of subscribers outside the United States. However, the increase in paid subscribers in this country during the past year has been very gratifying. It is hoped that the Society can continue to make up for losses of foreign subscriptions by the increase in our own country.

The policy of dropping members and subscribers for non-payment after six months delinquency has undoubtedly helped to speed up payment of dues and subscriptions. Before any members were dropped from the rolls they were sent three notices of dues, two of which asked them to reply if they were unable to send in their remittance at that time. If no reply was received from any of these notices, the members were dropped July 1. The same policy was applied to subscribers. This is a very lenient policy as compared to other scientific societies. It is hoped that the date for dropping delinquent members and subscribers can be further advanced during the coming year.

The Secretary appreciates the fine cooperation which the members have given during the past year. The valuable aid of state representatives in securing new members and the prompt and efficient work of the program chairmen deserve particular mention.

Respectfully submitted,

G. G. POHLMAN, *Secretary.*

REPORT OF THE TREASURER

I BEG to submit herewith the report of the Treasurer for the year, November 1, 1939 to October 31, 1940.

RECEIPTS

Miscellaneous	$ 29.00
Convention receipts	1,087.00
Advertising income	882.46
Reprints sold	1,377.33
Journals sold	167.31
Subscriptions, 1939	334.16
Subscriptions, 1940	2,279.20
Subscriptions, 1940 (new)	448.69
Subscriptions, 1941 (advanced)	208.23
Dues, 1939	555.59
Dues, 1940	4,795.26
Dues, 1940 (new)	605.17
Dues, 1941 (advanced)	59.00
Index	46.70
Miscellaneous (S.S.S.A.)	368.80

Sale of Soil Survey Bulletins (Marbut Memorial Fund)	$ 87.60
Sales of Proceedings, Vol. I (1936)	199.46
Sale of Proceedings, Vol. II (1937)	155.45
Sale of Proceedings, Vol. III (1938)	406.63
Dues and Subscriptions S.S.S.A. 1940	2,388.17
Dues and Subscriptions S.S.S.A. 1940 (new)	288.50
Dues and Subscriptions S.S.S.A. 1941	28.00
Membership only, S.S.S.A., 1940	27.00
Sales of I.S.S.S. Proceedings and Transactions	144.38
Fees, I.S.S.S., 1939	55.00
Fees, I.S.S.S., 1940	706.30
Fees, I.S.S.S., 1940 (new)	57.00
Total receipts	$17,787.39
Balance in cash, November 1, 1939	1,973.14
Total income	$19,760.53

DISBURSEMENTS

Printing the Journal, cuts, etc		$ 8,060.08
Salary of Business Manager and Editor		735.00
Postage, Business Manager and Secretary		131.44
Printing, miscellaneous		165.60
Express		13.12
Mailing clerk and stenographer		1,263.07
Refunds, checks returned, etc		99.04
Expenses for meetings		1,238.13
Miscellaneous		191.18
S.S.S.A. expenses, printing proceedings, etc		4,248.85
I.S.S.A. expenses, fees to Dr. Hissink, etc		928.79
Total disbursements		$17,074.30
Total income	$19,760.53	
Less total disbursements	17,074.30	
Balance in checking account October 31, 1940	$ 2,868.23	
Balance in trust certificate	267.71	
Balance in savings bonds	2,340.00	
Total assets		$ 5,293.94

Respectfully submitted,
G. G. Pohlman, *Treasurer.*

REPORT OF THE AUDITING COMMITTEE

THE Committee have examined the books of the Treasurer and find the accounts correct as reported.

L. A. Richards
F. B. Smith, *Chairman*

OTHER COMMITTEE REPORTS

BIBLIOGRAPHY OF FIELD EXPERIMENTS

THE committee has compiled a bibliography of 45 titles of the more important contributions on the methodology of and interpretation of results of field plot experiments, either reported since or not included in the revised bibliography published in the Journal (Vol. 25: 811–828, 1933; and the additions in Vol. 27: 1013–1018, 1935; Vol. 28: 1028–1031, 1936; Vol. 29: 1042–1045, 1937; Vol. 30: 1054–1056, 1938; Vol. 31: 1049–1052, 1939).

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F. R. IMMER
H. M. TYSDAL
H. M. STEECE, *Chairman*

PASTURE IMPROVEMENT

GRASSLAND CONFERENCES

FOR the past few years the primary study of the Committee on Pasture Improvement of the American Society of Agronomy has been the relative value of various crops used as pasturage, hay, silage, or grain when grown under comparable soil and climatic conditions. In America's trend toward a grassland agriculture it is evident, and essential, that greater consideration be given to the productivity of various forage and pasture crops as compared to other harvested feed crops, and to the relative differences in composition and feeding value. Greater consideration of these and related problems was brought about by encouraging and assisting with a series of five special "Grassland Research Conferences" usually in conjunction with other meetings, especially the summer meetings of the American Society of Agronomy. Such conferences are particularly successful in the summer when the specialists have an opportunity to examine and study the investigational work under way in the various sections of the country.

When arrangements were under way for these Regional Technical Grassland Conferences, the question was repeatedly asked as to when the public was to

be taken into our confidence as to our objectives, procedures, progress to date, research needs, etc. The Pasture Improvement Committee considered the desirability of the group, sponsoring, or assisting regional groups with general meetings to which the public would be invited, these general meetings to be held for one or two days immediately following the technical conferences. By the public we had in mind state and federal workers and the agricultural leaders in the region —that is, leaders of farm organizations, outstanding farmers, ranchers, county agents, action agencies, industries, railways, etc. Two types of regional conferences were considered—first, informal conferences of technical workers directly concerned with pasture and grass investigations, and second, a general conference open to the public at which agricultural leaders in the region would be asked to participate.

In order to bring about a coordinated approach to the organization of the conferences in the several Bureaus of the U. S. Department of Agriculture, the Secretary of Agriculture appointed a Departmental Committee to work with and assist local committees in each region. The Head Agronomist in Charge of the Division of Forage Crops and Diseases in the Bureau of Plant Industry was appointed chairman of the Departmental Committee. The Northeastern Committee was headed by Dean S. W. Fletcher; the Southeastern by Director S. H. Starr; the Western by Director William Peterson; the Northcentral by Dean R. E. Buchanan, and the Southern Great Plains by Prof. R. I. Throckmorton and Dr. E. R. Henson.

The Regional Grassland Conference in the Northeastern Section of the country was held at State College, Pennsylvania, July 10–12. The Conference was officially sponsored by the Northeastern Section of the American Society of Agronomy and by the Pasture Improvement Committee of the Society. The program consisted of three general sessions: (1) "General Perspective", (2) "Adjustments in Farm Practices as Affected by Grassland Agriculture", and (3) "Educational Objectives of a Grassland Agriculture". Approximately 250 people attended this Conference. The collaborators of the U. S. Regional Pasture Research Laboratory had its annual technical conference just preceding the Grassland Conference and the Northeastern Section of the American Society of Agronomy had its annual summer meeting immediately following.

The Regional Grassland Conference in the West was held at Salt Lake City, Utah, July 15–17, and about 250 people came out to these meetings. The Conference was officially sponsored by the Pasture Improvement Committee of the American Society of Agronomy. The staff of the Range Research Division of the Forest Service took an active part in assisting with arrangements. The meeting was held immediately following the summer meeting of the Western Section of the American Society of Agronomy. The program was opened with a general discussion of "Grass in Western Agriculture", then followed six general sessions: (1) "Pastures", (2) "Grass on Range Lands", (3) "Grass as a National Resource", (4) "The Place of Grass in Soil and Water Conservation", (5) "Grassland Research", and (6) "Grass and the Public". The final day of the Conference was devoted to a tour of pasture and range areas.

The Regional Grassland Conference in the Southeastern Section of the country was held at the Georgia Coastal Plain Experiment Station, Tifton, Georgia, July 25–26. The Conference was officially sponsored by the Association of Southern Agricultural Workers and the Pasture Committee of the American Society of Agronomy. The program consisted of three general sessions, as follows: (1) "General Perspective", (2) "Economic and Social Impacts of a Grassland Agri-

culture", and (3) "How to Achieve a Grassland Agriculture Suitable to the South". The afternoon of the first day was devoted to nine group discussions on pertinent grassland problems. Each afternoon field excursions were organized to visit pasture and grass breeding plots on the Experiment Station. The meeting had an enthusiastic attendance of about 500 people. At the annual meeting of the Association of Southern Agricultural Workers in Birmingham last winter, a group of specialists interested in pasture and forage crop research organized the "Southern Pasture and Forage Crop Improvement Committee". This group sponsored a two-day technical conference just preceding the Southern Grassland Conference. The Pasture and Forage Crop Improvement Committee of the Association of Southern Agricultural Workers plans to sponsor a technical conference each year at one of the southern institutions.

The Southern Great Plains Regional Grassland Conference was held in Amarillo, Texas, September 5 and 6. The Conference was officially sponsored by the Southern Great Plains Agricultural Council, and was well attended by a group of about 350 interested guests. The Regional Coordinator's Office and the Soil Conservation Service assisted greatly with the organization of the Conference. The program was divided into four general sessions: (1) General perspective and problems involved, (2) Revegetation and grass improvement, (3) Economic and management problems, and (4) Panel discussion—"Forwarding a Grassland Agriculture". A five-day tour beginning at Woodward, Oklahoma, and passing through Southwestern Kansas, Southeastern Colorado, and ending at Amarillo, Texas, in time for the Grassland Conference, preceded the Conference.

The Northcentral Regional Grassland Conference was held at Ames, Iowa, September 11, attended by about 300 people. The Conference was officially sponsored by the Corn Belt Section of the American Society of Agronomy and the Association of Northcentral Experiment Station Directors, of which Dean W. C. Coffey of Minnesota is chairman. The program of four general sessions was as follows: (1) "The Use of Grass in Adjusting Production", (2) "Research Contributions and Needs", (3) "Education and Application", and (4) "Problems in Adjustment". The annual summer meeting of the Corn Belt Section of the American Society of Agronomy was held immediately preceding the Grassland Conference. The field demonstrations by the staff of the Iowa State College were directed toward the problems and possibilities of grassland development in the Corn Belt.

The Regional Grassland Conferences in the various sections of the country seemed to meet with much favor. In two regions invitations have already been extended by universities to continue the Conferences in some form next summer. A survey among those in attendance at these Conferences during the past year seemed to indicate that it would be desirable to have Regional Grassland Conferences at least once in 3 to 5 years, inviting the agricultural leaders to participate. More immediate needs, however, are Regional Conferences of technical workers to provide an opportunity to exchange ideas by way of informal discussion of methods and technics for carrying on grass and pasture research. Such a group, composed of collaborators of the U. S. Regional Pasture Research Laboratory at State College, Pennsylvania, has been formally organized in the Northeastern region. In the Southeast the Technical Conference will be sponsored annually by the Pasture and Forage Crop Improvement of the Association of Southern Agricultural Workers. In the Northcentral region a group has been meeting informally for a number of years with the summer meeting of the Corn Belt Section of the Agronomy Society. During the past summer this group gave

way to the general Grassland Conference held at Ames, Iowa. In the Mountain States technical conferences may be continued in the future in close association with the Range Management staff of the Forest Service, and in the Southern Great Plains, with the various agencies concerned with the revegetation and range problems common to the "Dust Bowl" and adjacent territory.

Many excellent papers were presented at the 1940 Regional Grassland Conferences and numerous inquiries and requests for copies have been received. A number have been mimeographed for preliminary distribution or publication in various trade and technical journals. Mr. Gove Hambidge, editor of the U. S. Department of Agriculture Yearbook, is considering the possibility of publishing these papers in the form of a Grassland Conference report or regional grassland pamphlets.

While the primary aim of the Regional Grassland Conferences is to bring together the technical workers such as agronomists, soil, range, dairy, livestock, nutritional, farm management, and economic specialists, leaders of farm organizations, extension workers, county agents, and specialists in agricultural departments of industries, railroads, and financial institutions, there is still the need to bring the grassland problems and methods for improvement to the attention of the farm and ranch operators. Several state institutions have proceeded to make arrangements for State Grassland Conferences. This is a desirable development and it is hoped that the local interests will proceed with such plans. Reports have also been received to the effect that a number of the institutions are making arrangements for "Grassland Days" at their annual Farm and Home Week. One of the industrial organizations has also formulated plans for local Grassland Research Conferences to bring to the attention of the specialists in this field the progress to date and future needs.

The program and activities of your Pasture Committee have been rather intensive during the past year, but the work has been facilitated by the cordial cooperation and support of the local institutions where the meetings were held, and by the many people throughout each region who presented papers and participated in the program. The publicity organizations too did a fine job of supporting the Conferences. Your Committee is very grateful indeed for all of this assistance.

DEVELOPMENT OF METHODS AND TECHNIC FOR GRASSLAND RESEARCH

Interests of specialists in soils and crops, range management, dairying, livestock production, nutrition, farm management, and botany and ecology have been sufficiently diverse to justify organizing separate professional groups or societies. Several of these organizations have recognized the importance of pastures by appointing standing committees to give special consideration to pasture problems. The development of improved methods and technics for measuring or evaluating pastures has been a problem common to all of these groups, and in recent years has received their special attention. Investigators concerned with such pasture research have compared notes and exchanged ideas. The need for coordination of efforts to develop uniform or improved technics has been apparent to the many workers who are attempting to measure or evaluate in some way the same or similar kinds of grasses and management practices.

A "Preliminary Presentation on Pasture Investigations and Technique", embodying the recommendations of the pasture committees of the American Society of Agronomy, American Dairy Science Association, and the American

Society of Animal Production, was issued as a report in 1935. In 1937 the Canadian Pasture and Hay Committee was added to the Inter-Society Committee.

It is now five years since the first report, "Preliminary Presentation on Pasture Investigations and Technique", was published. The Pasture Committee of the Dairy Science Association, at its annual meeting this year, did a thorough job of revision as far as their special interests are concerned. At the Regional Grassland Conferences held this summer emphasis was placed on the development of "methods" and many new and constructive suggestions were brought out and discussed. The collaborators' conference of the Northeastern States at the U. S. Regional Pasture Research Laboratory, devoted its entire meeting this year to methods of measuring and evaluating pasture experiments.

It is desirable that the valuable material developed at these conferences, and from other sources, be brought together in the contemplated revision of the report of the Joint Committee on Pasture Improvement. Committee members have urged the calling of a conference of the Joint Pasture Research Committee at Chicago this fall to consider the numerous suggestions and prepare a revised report and, accordingly, a meeting of the Joint Committee has been arranged for December 3, 1940, immediately following the annual meeting of the American Society of Animal Production and preceding the meeting of the American Society of Agronomy. This will be the first meeting of the Joint Committee since its organization in 1935.

The Inter-Society organization of the four mentioned Committees is known as the "Joint Committee on Pasture Research". It is recommended that the name of the "Joint Pasture Improvement Committee" of the American Society of Agronomy be changed to "Pasture Improvement Committee" of the American Society of Agronomy to avoid confusion when reference is made to the respective committees.

Henry L. Ahlgren
B. A. Brown
D. R. Dodd
C. R. Enlow
R. D. Lewis
Robert Lush
O. McConkey
George Stewart
J. D. Warner
O. S. Aamodt, *Chairman*

EXTENSION PARTICIPATION

WE ARE pleased to report a good attendance of Extension Agronomists at this meeting and we express our appreciation of the fact that the two Extension Agronomists have a place on the program.

Since the Extension Agronomist has a close contact with the farmer and knows what is going on in the field, he should be in a position to make valuable contributions to the programs of the Society. This viewpoint is often needed to round out properly the discussion of many problems.

We therefore recommend that the Chairman of the Committee on Extension Participation be made a member of the program committee.

J. C. Lowery
O. S. Fisher
Earl Jones
E. L. Worthen
E. R. Jackman
L. L. Compton
J. S. Owens, *Chairman*

SOIL TILTH

THE Joint Committee on Soil Tilth, in their report to the 1939 meeting, attempted to call attention to the various physical properties of the soil that are implied in the term "soil tilth". Evidence was presented to indicate that the concept of tilth included certain structural properties of the soil that are exhibited within a given range of soil consistency. A short discussion of porosity and penetrometer methods for measuring tilth was included.

The Committee is no more prepared to offer a good definition of "tilth" than they were a year ago. The majority of the Committee, however, feel that the term as now used includes both of the following factors, *viz.*, workability and structural conditions favorable for plant growth. The suggestion is offered that some attempt be made to clarify the terminology so as to distinguish between these two concepts. This can only be possible after a careful solicitation of the views of various soil investigators.

Field and laboratory studies at the Ohio Agricultural Experiment Station during the past year have produced some encouraging preliminary results in the correlation of penetrometer and porosity data as expressions of soil tilth. A part of these results will appear in the 1940 volume of the Soil Science Society of America PROCEEDINGS. Further research is necessary to evaluate the importance of these measurements for characterizing tilth.

The Committee make the following recommendations for the coming year:

1. That an attempt be made to clarify the definition of soil tilth by enlisting the cooperation of interested soil investigators.
2. That the Committee should stimulate interest between soils men and agricultural engineers to cooperate on projects involving tilth problems. Such cooperation is now in progress at a few institutions.
3. That the Committee encourage more research on the importance of tilth in crop production.

J. F. LUTZ R. J. MUCKENHIRN
H. E. MIDDLETON L. D. BAVER, *Chairman*

STUDENT SECTIONS

THE following institutions have petitioned for charters in the Student Section of the American Society of Agronomy: Southwestern Louisiana Institute; University of North Carolina; and University of Georgia. The addition of these three chapters makes a total of 23 institutions with affiliated clubs.

During the past year the Society has prepared certificates of membership in the Student Section. These certificates are distributed free of charge to the members of the various chapters.

The essay contest topic was "Causes of Rundown Pastures and Methods of Their Improvement." The authors of the ten best papers were 1, John Lonnquist, University of Nebraska; 2, Milo B. Tesar, University of Nebraska; 3, Theodore H. Johnston, University of Nebraska; 4, Henry H. Hadley, University of Illinois; 5, Will Pitner, University of Nebraska; 6, Earl R. Leng, University of Illinois; 7, Andrew J. Andresen, University of Nebraska, and Richard L. Wood, University of Illinois (tie); 9, Lloyd C. Jones, Kansas State College; and 10, Robert L. Coolidge, Pennsylvania State College.

It is recommended that the abstracts of the three highest ranking papers be printed in the JOURNAL as a part of this report.

CAUSES OF THE RUNDOWN CONDITION OF THE WESTERN RANGE AND METHODS OF IMPROVEMENT

John Lonnquist, University of Nebraska

THE importance of the western range as a grazing region can be observed by the fact that 75% of the wool and mohair produced in this country comes from the western range and the total number of livestock in the area, according to the 1930 census, was over 63 million head valued at 1.4 billion dollars. From the period 1870 to 1920, this vast area was grazed with increasing intensity reaching a peak of 22.5 million animal units in 1920. After the war, livestock numbers declined rapidly until in 1934 the estimated carrying capacity was 10.5 million animal units. This tremendous reduction in carrying capacity resulted from faulty grazing practices and poor grazing management, which reduced the density of the vegetation of the area to about 52% of its virgin condition.

Overstocking has been the primary cause of range depletion. Premature grazing resulting from the stockmen's inability to provide sufficient winter feed for vast herds of stock has also been a serious factor in range depletion. The vegetation is eaten off before it has grown large enough to replenish the supply of organic root reserves used in renewal of growth in the spring. Thus, the vegetation becomes weakened and may be actually starved out. Burning has been used to bring about earlier growth of vegetation and consequently earlier range use, thus causing further damage from premature grazing. Lack of planned distribution of salting and watering places has had its effect on range depletion through excessive trampling and overgrazing around these areas when located too far apart.

Drouth decreases density of native vegetation, especially if prolonged for several years. Ranges adequately stocked during a normal season may become badly overstocked during a period of drouth unless the number of livestock is adjusted accordingly.

Erosion has resulted from decreased density of vegetation due to drouth and unwise grazing practices. It is, however, a factor in range deterioration as it destroys good land through gully formation and silting over of bottomlands.

Range improvement is concerned chiefly with the restoration and maintenance of the important forage species so that maximum production of forage is maintained from year to year.

Plant indicators are indispensable in determining whether ranges are being properly used or are being misused. Certain plants indicate a healthy range, while others may indicate various stages of range depletion.

Natural revegetation has been successfully accomplished by use of a deferred and rotational grazing system. The range is divided into three or four areas. One of these is then protected from grazing until seed has matured. The same area is again protected the following year until seedlings have become established. Each area receives the same 2-year treatment in a definite rotation.

Delaying grazing in the spring until the more important species have attained a height of 6 to 8 inches minimizes the damage from too early grazing. Ranges dominated by certain species may adapt themselves to seasonal grazing, depending upon the length of time the vegetation remains palatable.

Natural springs and seeps should be supplemented by construction of reservoirs located in such a manner that a wider utilization of the range is obtained. Proper distribution of salt away from watering places is of great help in attracting stock into unused areas.

Artificial reseeding as a means of restoration of range forage grasses has been successful only on areas where conditions were far above average. Where a few native species remain to furnish seed, natural revegetation, through deferred and rotational grazing, has been most satisfactory.

Moisture conservation and erosion control on the western range are possible only by maintenance of maximum density of vegetation.

CAUSES OF THE RUNDOWN CONDITION OF THE WESTERN RANGE AND METHODS OF IMPROVEMENT

Milo Benjamin Tesar, University of Nebraska

THE western range is an integral part of the nation's agriculture because it furnishes feed for over 11,000,000 animal units. Located west of the one-hundredth meridian, its 728,000,000 acres produce 75% of the wool and mohair, 55% of the sheep and lambs, and about 33% of the cattle produced in the entire United States.

This range area, which is one of America's greatest unrecognized resources, is today depleted to the extent of 52% of its virgin condition. It was once capable of carrying 22,500,000 animal units; today it carries only 10,800,000 units.

The three principal causes for the rundown condition of the western range are overgrazing, premature grazing, and continuous grazing. Most investigators are agreed that overgrazing is the main cause of the deterioration. It has reduced the ranges from 20 to 65% in grazing value. Closely related to overgrazing is premature grazing which depletes the stored root reserves of carbohydrates and decreases the quantity of forage and roots. Experiments by Aldous and others indicate that close continuous grazing reduces forage yields by about 25%, and that persistent grazing will eventually kill any established stand of grass.

Reports by various investigators show that a large percentage of the native grasses in the western range was killed by the drouth of 1934. This situation was aggravated further by the faulty distribution of livestock, a condition which resulted in uneven range utilization. Although other causes, such as burning, erosion, and rodent damage, have hastened the depletion of the range area, their effects would not have been serious if the range had been grazed conservatively.

The depleted condition of the range can be improved if proper methods are initiated. Such methods have been applied successfully in the national forests and the Sandhills of Nebraska where ranges are now in excellent condition.

The use of plant indicators as a guide to the intensity of range depletion is necessary. Range land that is moderately grazed may be reclaimed by the application of a deferred and rotational system of grazing. This consists of dividing the range into from two to five units and deferring grazing on a different unit each year until the seed crop has matured, thereby resting and grazing the units in rotation. Strategically located salting and watering stations on this range land will help materially in preventing undergrazing and overgrazing on the same area.

Those ranges that are eroded and are almost denuded of vegetation can be reclaimed only by reseeding with adapted species and by permitting the newly established vegetation to prevent further erosion. The use of native species in the Southwest and of adapted introduced species near the Dakotas and Montana is recommended.

Weeds and brush on a range should be eradicated by cutting or burning. Aldous states that most weeds can be destroyed by cutting annually during

the beginning-bloom stage at which time root reserves are lowest. A similar effort to control rodents by trapping, shooting, or poisoning should be started to insure the success of the range re-vegetation program.

CAUSES OF RUNDOWN PASTURES IN NORTHEASTERN UNITED STATES AND METHODS OF THEIR IMPROVEMENT

Theodore H. Johnston, University of Nebraska

MAJOR causes of rundown pastures in northeastern United States have been found to be low soil fertility, overgrazing, presence of undesirable plant species, poor stand of desirable species, erosion and improper drainage, and, to a lesser extent, burning. Low fertility of the soil is probably the chief cause in this area.

The type of pasture to improve is very important. Factors to consider include distance from farm buildings, accessibility to water, productivity of the land, available soil moisture, and several others.

Probably the most important method for improving pastures in this section is to increase the soil fertility. This can best be done by applying the necessary elements of fertility in proper amounts. Nearly all soils in this region have undergone excessive leaching, leaving them somewhat acid and therefore requiring lime. Phosphate fertilizers are needed on most soils in this section, while potash is needed to some extent. Available nitrogen is very essential for high yields of herbage and is supplied largely by the growing of legumes, especially white clover. If nitrogen is not supplied in sufficient quantities by legumes, then application of nitrate fertilizers is necessary. Manure has not been a very satisfactory source of nitrogen for pastures.

Certain plant species are much more desirable for pastures than others and the stands of such species can be improved by proper fertilization and re-seeding where necessary. White clover is probably the most important pasture legume, while several other clovers are grown to a considerable extent. Leading pasture grasses are Kentucky bluegrass, the bent grasses, redtop, orchard grass, and timothy. If new pastures are seeded, it is advisable to use a recommended pasture mixture. Various species differ in their adaptations and use of mixtures aids in establishing forage stands whatever the season.

Eradication or control of undesirable species can best be accomplished by increasing the growth of desirable species through proper fertilization and proper grazing. In this way most of the weeds are crowded out. Mowing weeds at the proper stage of development is likewise very effective.

The first essential practice in proper pasture management is prevention of too early grazing in the spring. Grazing should not be delayed too long, however, or much of the value of the herbage is lost.

Many of the pastures in this area are kept at a high level of production by following a system similar to the Hohenheim system of intensive pasture management. Under this method, heavy nitrogen fertilization and close, rotational grazing are practiced.

Supplementary pastures are needed during midsummer when permanent pastures are at a low level of production. Sudan grass has been found to be one of the best pasture crops for this period. Rye, millet, and meadow aftermaths may also be used.

Cultural practices which are deemed advisable include harrowing to scatter

droppings, use of a roller in spring if necessary, and mowing where grazing has been uneven. This mowing makes more uniform growth possible and helps to insure more uniform grazing.

G. H. Dungan	M. B. Sturgis
A. L. Frolik	J. W. Zahnley
J. B. Peterson	H. K. Wilson, *Chairman*

FERTILIZERS

Subcommittee on Soil Testing.—The results of 38 collaborators who have submitted their soil test results on the series of check soils assembled last year have been compiled and compared with reference to (1) effect of method on results obtained; (2) consistency of data of various individuals using the same methods; and (3) indications of the average results by soil tests with reference to the field records of crop production and response to treatment.

A comprehensive summary of these comparisons was presented before the general meeting of the Fertilizer Committee on December 3, and will appear in the mimeographed proceedings.

Further data on these soils with reference to laboratory determinations of exchangeable bases, available phosphorous and such other related chemical studies as may be made at various research laboratories will be compiled by the committee. Cooperation along these lines will be welcomed.

Correlations of soil test results and interpretations in terms of specific recommendations between soil testing agencies in regions of similar soils and cropping practices should be fostered by the distribution of samples of a few soils representing typical problems from several state soil testing laboratories, to others in their localities. It is suggested that this subcommittee serve as a clearing house for information obtained in such studies.

The special problem of phosphorous testing of soils of the semi-arid portions of the United States, especially those containing large amounts of carbonates, should be given increased attention. None of the present methods giving useful results in the humid region are likely to prove applicable to such conditions, although they are now being used in some instances. Research along this line will be encouraged by the committee.

The Committee sponsored the presentation of a program of your papers before the general meeting of the Fertilizer Committee.

M. F. Morgan, *Chairman*

Subcommittee on Fertilizer Grades.—The Committee has continued its efforts toward (1) reduction of the number of grades recommended for use and offered for sale within a given state, (2) more unity in recommendation in adjoining states, and (3) making adjustments between lists of recommended grades and lists of grades offered for sale. The fertilizer industry has shown a willingness to cooperate in the reduction of the number of grades offered for sale and in harmonizing the list of grades offered with the list of recommended grades. This cooperation is greatly appreciated by the Committee and by agronomists.

Through the cooperation of the National Fertilizer Association an article prepared by D. D. Long, of this Committee, entitled "Reducing the Number of Fertilizer Analyses", was published in the August issue of *The American Fertilizer*. In this article the cost to manufacturers of producing a large number of grades is stressed.

In six states the number of grades offered for sale is limited to grades recommended for use by state officials. This arrangement is by agreement between manufacturers and state representatives. In states not limiting the number of grades offered for sale, sales of grades recommended for use constitute from 4 to 85% of total sales of mixed goods.

The plant-food survey compiled by the Bureau of Plant Industry and National Fertilizer Association shows that 982 grades constituted 90.7% of tonnage of mixed goods in 1939, whereas 1,291 grades accounted for only 78% of total tonnage in 1934. Furthermore, 10 grades accounted for two-thirds or more of the consumption of mixed fertilizer in all but two states in 1939. These data show definite reduction in number of grades purchased and also that a comparatively few grades will satisfy the demand in most states.

In many cases, very slight differences exist between grades recommended in neighboring states and also in grades sold in such states as 0–14–6 vs. 0–14–7, 5–8–5 vs. 4–8–5, 4–8–7 vs. 4–8–8. Such minor differences could easily be eliminated by cooperative effort.

Agronomists who have not done so are urged to prepare a list of recommended grades. Even though faulty, such a list furnishes a basis for cooperation between the industry and state officials which will lead to a reduction in number of grades offered and a higher utilization of recommended grades. Annual or biennial conferences between agronomists of states with similar soil conditions and cropping systems and manufacturers serving the territory are urged in the interest of unity in grade recommendations and increased sale of recommended grades.

C. E. MILLAR, *Chairman*

Subcommittee on Methods of Fertilizer Application.—The Committee has continued to participate in the work of the National Joint Committee on Fertilizer Application. The extensive program on machine application of fertilizers has been continued and last year included 149 experiments in 24 states and involved 24 different crops.

Considerable attention is being given to the use of starter solutions at planting time, and thirteen experiments in seven states involving cabbage, sweet potatoes, tomatoes and Irish potatoes were conducted during the year.

A promising phase of the fertilizer placement work has dealt with the plowing under of fertilizers, either with or without organic residues, as a means of increasing the efficiency of fertilizer supplements to row application.

To an increasing degree interpretive studies of root development, movement of fertilizer salts in the soil, etc., are being made in connection with fertilizer placement studies in an effort to discover the fundamental principles involved.

ROBT. M. SALTER, *Chairman*

Subcommittee on Symptoms of Malnutrition in Plants.—The Committee is glad to report that its efforts to prepare and publish a book illustrating in color and describing the more important malnutrition symptoms of the major crop plants appear to be approaching a successful conclusion. The material for the book, most of which has been submitted and edited, has been prepared by the following chapter authors: Foreword by Gove Hambidge; background by George D. Scarseth and R. M. Salter; tobacco by J. E. McMurtrey, Jr.; cotton by H. P. Cooper; corn and small grains by G. N. Hoffer; potatoes by H. A. Jones and B. E. Brown; vegetable crops by J. J. Skinner; legume crops by E. E. DeTurk; deciduous fruits by O. W. Davidson; and citrus fruits by A. F. Camp, H. D. Chapman, George M. Bahrt, and E. R. Parker.

The prospectus announcing the book "Hunger Signs in Crops", was placed on display at the Chicago meeting of the Society. It describes in detail the proposed edition consisting of about 80 natural color plates and many additional illustrations. The descriptive material and illustrations will make up a book of about 300 pages.

It is expected that the book can be published at a cost of $2.00 per copy, prepublication price, with an edition of 10,000 copies.

The following procedure on publication has been recommended by the Committee and approved by the Executive Committee of the Society: First, that the book be published by the Committee on Fertilizers of the American Society of Agronomy with the cooperation of the National Fertilizer Association; and, second, that the copyright be assigned to the American Society of Agronomy and the National Fertilizer Association, but that the copyright, as printed in the publication, read merely, "Copyrighted in 1941". It is also recommended that there be an understanding with the copyright owners that any material included under the copyright can be used by the contributing authors at any later date as they may see fit.

J. E. McMurtrey, Jr., *Chairman*

Subcommittee on Fertilizer Reaction.—The Committee on Fertilizer Reaction was established in 1935 when the fertilizer industry, the Association of Official Agricultural Chemists, and agronomists were studying the equivalent acidity of fertilizers. The initial work of the committee was devoted to promoting experiments aimed at the solution of several of the problems involved. Since the formation of the committee, the Association of Official Agricultural Chemists has adopted the Pierre Method for use in fertilizer control work. Six Southeastern states now require a guarantee for the acid-forming properties of fertilizers. Several other states determine and report the equivalent acidity of fertilizers. The fertilizer industry is guaranteeing the acid-forming properties of their fertilizers in many states, including a number that do not require such a guarantee. In the past five years, numerous field experiments have been conducted which involve a comparison of acid, neutral, and basic fertilizers. Many of these experiments are still in progress. Almost without exception the fertilizer acidity factor is given due consideration in planning new experiments and is also considered in the interpretation of data secured from older experiments. The results of extensive experiments in Mississippi were published in 1940 and showed an average increase of 90 pounds of seed cotton per acre due to addition of dolomite to make the fertilizer neutral.

In 1937, 1938, and 1939, the committee promoted studies on the availability of different sources of magnesia and the factors influencing the availability of magnesium in dolomite. These experiments were designed to help the Association of Official Agricultural Chemists arrive at a control method for available magnesium in fertilizers. The laboratory and greenhouse experiments have been completed and reported to the Association of Official Agricultural Chemists by Collins and Dawson. Some related work is being continued by Smith of Rhode Island, Associate Referee on magnesium for the A.O.A.C. as well as a member of this committee. Studies on this problem are being continued in the field at the Maine and Virginia Stations. None of the farm soils on which the experiments were located showed a response to magnesium in 1940.

Dr. W. H. Ross and his associates in the Division of Fertilizer Investigation of the U. S. Department of Agriculture has made a comprehensive study of the

reaction of magnesium compounds in fertilizers, including transformations of insoluble to soluble forms during the manufacture and storage processes. The results of these studies were reported at the 1940 meeting of the Fertilizer Division of the American Chemical Society and also at the Association of Official Agricultural Chemists.

The Subcommittee has encouraged field experiments on the influence of acid and neutral fertilizers on potato scab. Such experiments are in progress in North Carolina, Virginia, and Maine. More intensive studies on this and related subjects are being considered for next year's program. Such studies will include consideration of exchangeable calcium in the soil as well as the calcium content of the fertilizer.

F. W. PARKER, *Chairman*

VARIETAL STANDARDIZATION AND REGISTRATION

DURING the year, the following approved varieties were accepted by the Committee for registration on the basis of performance.

WHEAT

Marmin (Reg. No. 328) developed cooperatively by the Minnesota Agricultural Experiment Station and the U. S. Dept. of Agriculture.

OATS

Fultex (Reg. No. 92), Ranger (Reg. No. 94), and Rustler (Reg. No. 95) developed cooperatively by the Texas Agricultural Experiment Station and the U. S. Dept. of Agriculture.

Uton (Reg. No. 97) developed in cooperative experiments by the Utah Agricultural Experiment Station and the U. S. Dept. of Agriculture.

Vicland (Reg. No. 93) developed by the Wisconsin Agricultural Experiment Station.

Huron (Reg. No. 96) developed by the Michigan Agricultural Experiment Station.

BARLEY

Wintex (Reg. No. 9) developed cooperatively by the Texas Agricultural Experiment Station and the U. S. Dept. of Agriculture.

Compana (Reg. No. 10) developed cooperatively by the Montana Agricultural Experiment Station and the U. S. Dept. of Agriculture.

Barbless (Reg. No. 11) developed by the Wisconsin Agricultural Experiment Station.

SORGHUMS

Coes (Reg. No. 77) and Highland (Reg. No. 78) developed cooperatively by the Colorado Agricultural Experiment Station and the U. S. Dept. of Agriculture.

Descriptions of these varieties, and the yields and other records that form the basis for registration, are being prepared for publication in the JOURNAL.

In the Committee report submitted at the 1939 meetings at New Orleans, it was recommended that the registration of certain additional crops be approved and the Committee authorized to take necessary steps for their registration. It was also suggested that additional members be appointed on the Committee

to provide specialists qualified to act in the case of the new crops recommended for registration. No official action was taken on this recommendation, and it is again recommended that the Executive Committee approve the registration of improved varieties of red clover, sweet clover, alfalfa, flax, and rye, and that additional members be appointed to the Committee to care for their registration.

H. B. BROWN	H. K. HAYES	T. R. STANTON
J. A. CLARK	R. E. KARPER	G. H. STRINGFIELD
E. F. GAINES	W. J. MORSE	M. A. MCCALL, *Chairman*

RESOLUTIONS

THE Committee on Resolutions regrets to announce the passing of the following members of the American Society of Agronomy: Oliver W. Dynes and Harry P. Ogden of Tennessee, Burt L. Hartwell of Rhode Island, Jacob E. Metzger of Maryland, Adrian J. Pieters of Washington, D. C., John J. Pieper of Illinois, and B. D. Wilson of New York.

On behalf of the American Society of Agronomy the Committee make this announcement with deep sorrow and a feeling of real loss of the further achievements and companionship of our colleagues. Detailed accounts of the lives and attainments of these men are attached to this report, except where statements have already appeared in the pages of the JOURNAL.

O. S. AAMODT	J. D. LUCKETT, *ex-officio*
F. N. BRIGGS	F. D. KEIM, *Chairman*
R. I. THROCKMORTON	

OLIVER WESLEY DYNES

OLIVER WESLEY DYNES was born in Hornings Mills, Ontario, Canada, March 10, 1881, and died after an illness of a few hours in Knoxville, Tennessee, May 6, 1940. He graduated from North Dakota State College in 1907 and served his Alma Mater as Instructor and as Associate Professor in Agronomy, 1907–1914. He obtained his M.S.A. from Cornell University in 1912 and returned to that institution for further graduate work and as Instructor in Farm Crops, 1914–1920. He became Associate Professor of Agronomy at the University of Tennessee in 1920, Professor in 1925, and Head of the Department in 1928, and also Associate Agronomist of the Experiment Station in 1936. As a member of the American Society of Agronomy, he gave yoeman's service on various committees. He was a member of Alpha Zeta, Sigma Xi, and Phi Kappa Phi.

His career at Tennessee was that of a successful, sympathetic, and understanding teacher. He was beloved of the students to whom he was an inspiration and by whom he was dubbed affectionately "Daddy Dynes". His interest in his students was maintained after their campus days, and through the years he enjoyed the many warm friendships that grew out of the relationships between teacher and student.

His early background, environment, and experience were brought into an effective pattern with his scientific training and academic attainments. He was a well-trained scientist who implemented his knowledge into practical usefulness. Especially did he further the development and distribution of pure seed and he was particularly helpful to many engaged in the development of corn hybrids.

Professor Dynes was held in high esteem by his colleagues and academic associates. He was admired for his inherent modesty, kindly manner, and many lovable traits. His steadfast loyalty to his friends, and to his ideals was a dominant characteristic. Generosity, fairness in all his dealings, good will, and tolerance were characteristic traits that were supplemented with a keen delightful sense of humor. He laughed with, but never at others.

Oliver Dynes loved people in all walks of life and by them was loved. He enjoyed an extensive state-wide circle of friends, among those outside of teaching and research circles. His natural and unassuming bearing endeared him to those with whom he came into contact in his community life. He found time for and joy in his affiliation with the First Methodist Church of Knoxville, which he served actively as a member of the Official Board. He was active in Masonic organizations, from which he received many honors and by which he had been marked for further honor and distinction. He had served as Master of his Blue Lodge, High Priest of R.A.M., Thrice Illustrious Master of the Council, and Commander and Prelate of Knights Templar. At his death he was in the line of succession to become Grand Thrice Illustrious Master of the Grand Council of Tennessee. He was a 32° Mason and Secretary of Constance Chapter of Red Cross of Constantine. He was also a Shriner, member of the Royal Order of Jesters, and of Acacia Fraternity.

Professor Dynes married Carlotta Lillian Rowe of Dundalk, Ontario, Canada, September 5, 1917. She, one daughter, Velma, and one son, Russell, both now students in the University of Tennessee, survive him. To them he was the devoted husband and doting father. To them he left the heritage of the love and admiration of a community that appreciated his life of usefulness and helpfulness to others.

By those of us who knew him as fellow graduate student, teacher, academic associate, and loyal friend, the memory of Oliver Dynes will be cherished. His friendship was a blessing to those so fortunate as to come within its orbit.

In the death of Oliver Wesley Dynes, his family, friends, community, the University of Tennessee, and the state have suffered a loss, irreparable yet assuaged by the knowledge that this world is better because of his life of devoted service and the example set by him.—WALTER H. MACINTIRE.

BURT LAWS HARTWELL

BURT LAWS HARTWELL, formerly Director of the Rhode Island Agricultural Experiment Station, died at his home in Edgewood, Rhode Island, July 12, 1939. He is survived by his wife, May Louise Hartwell, and a daughter, Mrs. Roy B. Newton.

Doctor Hartwell was born near Littleton, Mass., December 18, 1865. His boyhood home was on a small Massachusetts farm. In 1889, he was graduated from Massachusetts State College and received his M.S. degree from the same school in 1901. He attended the fiftieth anniversary reunion of his class at Amherst in June, the month preceding his death. He received his Ph.D. degree from the University of Pennsylvania in 1903.

Doctor Hartwell came to the Rhode Island Agricultural Experiment Station in 1891 as Assistant Chemist. Later he attained the rank of Station Chemist and in 1912 he became Director of the Experiment Station. He served in this capacity until 1928, when he left the field of agricultural research. From 1928 until his death he was farm news editor of the Providence *Journal and Evening Bulletin*.

Doctor Hartwell's contributions to soils research are too well known to make it necessary to review them in detail. His outstanding contribution was perhaps his extensive research on soil acidity. Working with Dr. H. J. Wheeler in the early years of the Experiment Station, many fundamental projects on the response of different plants to soil acidity and methods of correcting this acidity were begun. In later years Doctor Hartwell was especially interested in the relation of the presence of toxic aluminum in the soil to soil acidity.

In addition to his extensive work on soil acidity and liming, Doctor Hartwell was also interested in the nutrient requirements of crop plants, and among his many publications are a large number dealing with this subject.

Doctor Hartwell became a member of the American Society of Agronomy soon after it was organized. He held a number of important committee positions and performed other assignments throughout his many years as an active member. He was elected a Fellow of the society in 1926.

In Doctor Hartwell's passing the science of agronomy lost one of its most faithful and outstanding workers.—T. E. ODLAND.

JACOB ELRY METZGER

JACOB ELRY METZGER, Director of the Maryland Agricultural Experiment Station and head of the Agronomy Department of the University of Maryland, died December 25, 1939, at Lake Worth, Florida, where he had gone for a vacation and rest. The cause of his death was coronary thrombosis.

Director Metzger was born on a farm near New Enterprise, Pa., July 30, 1882. Before entering Pennsylvania State College he taught several years in the elementary schools. He received his B.S. degree from Pennsylvania State College in 1911, in agricultural chemistry. The next three years were spent as an agricultural instructor in the high school at Fergus Fall, Minn. In 1914, he came to the Maryland Agriculture College, now the University of Maryland, as Professor of Agriculture Education and Supervisor of agricultural instruction for the Maryland State Department of Education. In 1917, he was appointed chairman of the Agronomy Department and continued in this capacity when the Soils and Agronomy Departments were combined in 1927, He received his A.M. degree from Johns Hopkins University in 1924. In 1935 he was made Assistant Director of the Experiment Station. On the retirement of Dr. H. J. Patterson in October 1937, he was appointed Acting Director, and in 1939, Director.

Although Director Metzger was especially interested in farm crops and rotations he had considerable interest in soils and related fields. This wide interest in agriculture is well demonstrated by the subject matter of the thirteen experiment station bulletins which he and his associates published. His greatest contribution to Maryland agriculture was that of a coordinator. His broad knowledge permitted him to see the value of related subjects and make suggestions for the improvement of the work of his associates. This outstanding ability was very noticeable when he assumed the directorship of the Experiment Station where his development of coordination between departments has resulted in the maximum of accomplishment from the funds expended. The Experiment Station staff and especially the members of his department regret very much that he was denied the pleasure of seeing the many benefits which will accrue from his efforts in the improvement of Maryland agriculture.

Director Metzger is survived by his widow, a brother, Dr. Irvin Metzger, M.D., of Pittsburgh, and three sisters, Mrs. Elry Furry, Mrs. Arch Furry, and Mrs.

Ira Kagarise, all living in Pennsylvania. Director Metzger was a fellow in the American Association for the Advancement of Science, member of the American Society of Agronomy, International Society of Soil Science, Masonic Fraternity, Kiwanis Club, Sigma Phi Sigma, Gamma Sigma Delta, Phi Kappa Phi, and Sigma Xi.—R. P. THOMAS.

HARRY P. OGDEN

HARRY P. OGDEN was born in Knoxville, Tennessee, November 10, 1888. He received his education in the Knoxville city schools and the University of Tennessee, being graduated from the latter institution in 1913 with the degree of Bachelor of Science in Agriculture. He died at his home in Knoxville, September 22, 1940, at the age of 52 years, after an illness of about one year.

He made a splendid scholastic record in the University and was elected to membership in the honor societies of Alpha Zeta and Phi Kappa Phi. After leaving the University he became head of the Science Department of the Clarksville High School; then Agricultural Agent for Montgomery County. He was next appointed to the position of Director of the Department of Agriculture at the State Teachers' College, Murfreesboro, where he conducted field experiments for the Experiment Station for several years. Returning to the University of Tennessee in 1926, he became Associate Agronomist at the Agricultural Experiment Station. In the experimental field he made contributions which will be of lasting benefit to the agricultural interests of the state and nation.

In particular he developed by breeding and selection three valuable varieties of soybeans, one of which has been named Ogden since his death. All three varieties are valuable because of their high production of both hay and seed. All are relatively fine stemmed but seldom lodge, and the seeds are exceptionally well retained in the pods, or "non-pop", to use a current expression.

Mr. Ogden was an especially valuable member of the station staff because of two outstanding qualities—an alert, practical mind and a devotion to detailed planning and careful conduct of experimental work. Another quality that endeared him to all members of the station staff was his willingness at all times to be of service by furnishing information and counsel in the solution of their problems so far as they were related to his knowledge and experience. Honest and sincere to the highest degree, cheerful and loyal, he will be missed by all his acquaintances.

He was married August 23, 1916, to Elsie Lapsley, who survives him with their children, Samuel Lapsley, Harry Kay, and Mary Frances.—C. A. MOOERS.

ADRIAN JOHN PIETERS

ADRIAN JOHN PIETERS, formerly Principal Agronomist in Charge of the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and a Fellow of the American Society of Agronomy, died at Sibley Hospital in Washington, April 25, 1940. He was in his seventy-fourth year.

Doctor Pieters retired from the Department in 1936 at the statutory age limit, but because of his wide knowledge of the use of soil-building crops the President twice reappointed him for a year's additional duty with the Bureau of Plant Industry and the Soil Conservation Service. Since 1938 he had been serving as Editor for the United States Golf Association Green Section.

Doctor Pieters was one of the early group of botanists, chemists, entomologists,

and agriculturists who, through their common interest in plants and soils, brought the science of agronomy into being. His own special training was in aquatic biology, but like his contemporaries, Lyon, Piper, Marbut, and others, his basic education was broad and his interests catholic. Thus, when the need arose, shortly after the turn of the century, he was fitted by circumstance and aptitude to become a "field-manager" or agronomist. Like these men, too, his personal qualities added stature to his technical equipment and gave distinction to his new profession. He personified dignity, culture, tolerance, and the judicial attitude, was indefatigable in the search for truth, and scorned sham or pretense whether social or intellectual. He was never known to loaf. Indeed, if criticism could be directed toward many of these men who created agronomy, it would be that they begrudged too earnestly the time spent in relaxation.

Doctor Pieters was of Dutch ancestry, a fact of which he was very proud. He was born in Alto, Wisconsin, the son of Roelof Pieters, a Dutch Reformed clergyman, and Hendricje Van Zwaluenburg Pieters. After a boyhood in Holland, Michigan, he graduated from the University of Michigan in 1894, then studied for a time at Cornell University. In 1895 he entered the Department of Agriculture as Assistant Botanist in Seed Investigations, under Gilbert Hicks. Almost immediately he was put in charge of a seed exhibit at the International exposition in Atlanta, the first exhibit of the kind ever shown by the United States Government. Curiously, one of the features of the exhibit was "a seed-scratching machine from Denmark", the forerunner by 20 years of seed scarifiers in America.

From 1900 to 1906 he was successively in charge of the Seed Testing Laboratory and the combined Offices of Seed and Plant Introduction and Distribution. In 1906 he resigned to engage in commercial seed production in California, establishing the firm that subsequently became the Pieters-Wheeler Seed Company. Having sold the seed business in 1910, he spent a year travelling in Europe and studying at Heidelburg University. He returned in 1912 to Ann Arbor, where he taught Forest Botany while working for his doctor's degree, which he received in 1915.

Shortly afterward he re-entered the Department of Agriculture, in the Office of Forage Crops to investigate the causes of widespread failure of the red clover crop. Soon he confirmed the belief that the principal cause was the use of seed from foreign countries, resulting in plants susceptible to disease and winter injury. He was instrumental, thereupon, in having restrictions placed on the importation of such seed.

It was during this study that Dr. Pieters was impressed with the futility of trying to make the soil fit the crop—by liming, principally—when the possibility of finding a crop to fit the soil had been only superficially investigated. He had in mind particularly the countless farms in the middle South whose owners were compelled, with meager resources, to get a living from depleted acid soils. He began, therefore, a long series of tests of legumes of many kinds, culminating, in 1920, in the finding of *Lespedeza stipulacea*, a new annual species which he called, from the country of its origin, "Korean lespedeza". This plant proved of tremendous value for it was found to grow, produce, and persist on poor, sour soils throughout the South. The discovery rekindled interest in the lespedeza group with such success that by 1938 the seed crop of the lespedezas—about 190,000,000 pounds—equalled the seed crops of alfalfa, red clover, and alsike clover combined.

Doctor Pieters was an able and fluent writer, his publications, numbering more than 80 titles, covering many phases of seed production, green manuring,

forage crop production, and soil conservation. Two books, "Green Manuring—Principles and Practices" and "The Little Book of Lespedeza", and two voluminous digests of pasture literature were among these.

Agronomy may well be proud that such men were its progenitors. Their characters are their eulogies and their works their valedictories.—L. W. KEPHART.

BENJAMIN DUNBAR WILSON

THE untimely death of Benjamin Dunbar Wilson, Professor of Soil Technology in the New York State College of Agriculture at Cornell University, was received by all who knew him even casually, with profound regret. His death occurred at Warren, Ohio, on September 5, 1940, four days after an auto accident in which he received internal injuries that later proved fatal. In his passing his special field of scientific endeavor loses a faithful and conscientious worker; his immediate associates an amicable and inspiring colleague; and his wide circle of friends an active and loyal advocate. He was kindly, considerate, and approachable. These attributes will not soon be forgotten.

Born on October 14, 1889, in Lexington, Kentucky, of Virginia and South Carolina ancestry, Dr. Wilson was educated in the local schools of that city and entered the University of Kentucky in 1906, specializing in chemistry with Dr. F. E. Tuttle. Graduating in 1909 with a B.S. degree, he accepted a position as assistant chemist in the Kentucky State Agricultural Experiment Station, at the same time pursuing work for the degree of Master of Science in the University. This degree was awarded in 1914.

The next three years were spent by the young scientist at Cornell University as a graduate student and assistant with Dr. T. L. Lyon of the Department of Agronomy. In June, 1917, Cornell University granted him the degree of Doctor of Philosophy. This same year Dr. Wilson was made an Instructor and two years later Assistant Professor of Agronomy in the New York State College of Agriculture at Cornell. He occupied the latter position until 1934. During these years he worked on various research projects and in close association with Professor Lyon. In 1934, Dr. Wilson was raised to a full professorship of Agronomy at Cornell University.

The special scientific work that occupied Professor Wilson's attention during the last ten years of his life was a chemical investigation of the peat soils of New York State. After a preliminary survey which added much to the knowledge of the character and extent of New York peat deposits, laboratory work was begun on representative profile samples. The following titles selected from his list of publications indicate the nature of the work in general: "The Chemical Composition of the Muck Soils of New York", "Ionic Exchange of Peat Soils", "The Character of the Peat Deposits of New York", and "Loss of Plant Nutrients from Peat Soil".

It is doubtful whether anyone has contributed as much fundamental scientific information respecting the peat soils of New York, and incidentally of northeastern United States, as has Professor Wilson. Yet he felt his work barely begun and apparently had before him many years of fruitful endeavor. His loss to science is to be regretted.—H. O. BUCKMAN.

NOMINATING COMMITTEE

THE Nominating Committee made the following report: Dr. R. J. Garber, Bureau of Plant Industry, as representative of the Society to the Union of Biological Sciences; Dr. F. E. Bear, New Jersey Agricultural Experiment Station,

and Dr. W. B. Kemp, University of Maryland, as representatives of the Society on the Council of the American Association for the Advancement of Science; and for Vice President of the American Society of Agronomy, Dr. Richard Bradfield of Cornell University.

Upon motion the Secretary was instructed to cast one vote for these nominees and they were declared unanimously elected.

Respectfully submitted,
G. G. POHLMAN, *Secretary*.

GUIDE TO CONTRIBUTORS TO THE JOURNAL OF THE AMERICAN SOCIETY OF AGRONOMY

IN EDITING copy submitted for publication in the JOURNAL of the American Society of Agronomy every effort is made to preserve, so far as possible, the individuality of the author's style. It seems desirable, however, that a certain degree of uniformity in the general arrangement of material published in the JOURNAL should be maintained, and the following suggestions are offered as an aid to those who prepare manuscripts for publication in this JOURNAL.

Contributions to the JOURNAL are not arbitrarily restricted in length, but free publication for any one contribution is limited to 12 pages. Additional pages are charged for at the rate of $4.00 per page for each page beyond the 12-page limit, to and including 16 pages, and at the rate of $5.00 per page for each page beyond 16.

GENERAL STYLE

Prospective authors are requested to study recent issues of the JOURNAL as examples of the general style of writing which is maintained as a standard and, so far as possible, to conform to that standard in the preparation of their articles.

Clear, concise, correct statements are desired, rather than long, involved sentences. Generally an account of an investigation should be written in the third person. The use of the first or second person is permissible when the personal views of the author or reader are the point at issue rather than the facts in the case.

The title of the article should be as brief as possible, but at the same time should convey an accurate impression of the contents of the paper.

The copy should be on standard weight paper 8½ x 11 inches and should be double spaced. The ribbon copy should be submitted, never a carbon copy. Tables and legends for illustrations should be on separate sheets.

HEADINGS

The logical presentation of the results of an investigation presupposes a definite outline prepared in advance. This outline should comprise a few main headings sufficiently subdivided to indicate clearly the relationship of the various parts of the discussion to the whole.

For most purposes it will be unnecessary to provide headings of more than three grades, *viz.*, main headings, secondary headings, and side headings. Excessive refinement in subdividing the text should be avoided. The main headings and secondary headings stand in the center of the page and are set in different size type to show their relative importance. Side headings are printed in italics, and almost invariably indicate subdivisions under the secondary headings. Only a small amount of text matter, preferably not more than a page, should be covered by a side heading.

Each heading should contain a substantive and should indicate the thing or things described or discussed in the text.

TABLES

All tabular matter should receive close study in order that it may be presented in the clearest possible manner. Arabic numerals are used in numbering tables in the JOURNAL.

Brief, explanatory legends are preferred, but the legend should be complete in itself so that the table can stand without reference to the text.

An example of a good heading is as follows:

TABLE 2.—*Effect upon yield of potatoes of spraying with paris green.*

The following is not a satisfactory heading:

TABLE 2.—*Results of first experiment.*

Where decimals occur in tabulated data, and elsewhere in the article, ciphers should be used wherever significant figures are lacking, otherwise omit the decimal point, as 29.55, 32.00, etc. Also, the decimal point should be preceeded either by a significant figure or by a cipher, as for example 1.25 or 0.25; not .25.

The following example is offered as a desirable form for presenting tabular matter in the JOURNAL.

TABLE 4.—*Germination of freshly harvested seed of Poa pratensis composited from greenhouse plants.*

Germinating conditions*	Total germination at†		
	2 weeks %	4 weeks %	6 weeks, %
20°–30° C	0	3	5
20°–30° C dark	1	9	11
Room temperature (22° to 26° C)	0	0	1
15°–30° C	11	47	77
15° C, dark, 10 days; then 20°–30° C	5	9	10
10°–30° C	14	87	91
10° C, dark, 10 days; then 20°–30° C	7	9	13
5°–30° C	0	4	5
5° C dark, 10 days; then 20°–30° C	0	28	29

*The lower temperature was maintained in darkness and the higher temperature in north light, except where otherwise noted.

†Each figure is the average of three replicates.

ILLUSTRATIONS

Drawings should be made on white drawing paper, or on blue or yellow lined graph paper. Do not use red or green lined graph paper unless it is imperative that the cross ruling be retained in the graph. All lines and lettering should be made with black india ink, and should be heavy enough to stand reduction to page size. The lettering along the ordinate or abscissa should be drawn in, as should all essential parts of the engraving.

The heading and general legend for the engraving should be typed on a separate sheet of paper, so it can be set up in type by the printer. Figures should be numbered consecutively, and should be referred to in the text by number, e.g., "Fig. 1."

In the case of photographs, contrasty, glossy black and white prints are desired. Only illustrations that will reproduce well in the JOURNAL and that make a distinct contribution to an understanding of the article will be accepted.

The JOURNAL bears the cost of zinc etchings and half-tones to the extent of $15.00 for each article, any costs in excess of this amount being charged back to the author.

QUOTATIONS AND REFERENCES

It is taken for granted in editing manuscript for the JOURNAL that the author assumes responsibility for the accuracy of quotations and literature citations, although occasionally these are verified where discrepancies are suspected.

In quotations the exact words of the original should be preserved. It is not essential in such cases, however, to reproduce typographical errors, or details of style, such as spelling, capitalization, or punctuation, which are at variance with the form approved by this JOURNAL, unless these differences are to be preserved for some particular purpose.

Literature citations if more than three should be grouped at the end of the article under the heading of "Literature Cited." Three citations or less should be given in footnotes.

Reference in the text to literature citations should be indicated by figures in parenthesis, for example, Brunson (1). The form of citation used in the JOURNAL is as follows:

1. BRUNSON, A. M. The relation of inheritance studies to corn improvement. Jour. Amer. Soc. Agron., 18:308–314. 1926.

In citations of experiment station publications the state names are abbreviated, as is also the United States Department of Agriculture, thus, N. Y. State Agr. Exp. Sta. Bul. 530; U. S. D. A. Bul. 1120.

CAPITALS

The word "state" should not be capitalized unless used with the state name, such as New York State. The word "county" should be capitalized if used before or after the name of the county, such as Ontario County. Terms applied to groups of states, as North Atlantic, South Atlantic, etc., should be capitalized, also terms denoting sections of the United States, as the West, the South, etc., but use eastern Gulf States, western New York, etc.

The terms "corn belt," "cotton belt," etc., should not be capitalized.

The words "experiment station" or "agricultural experiment station" should be capitalized only when used with the name of the institution, such as the Illinois Agricultural Experiment Station.

The names of genera, families, orders, etc., should be capitalized, but names of species should be written with lower case.

Words that have come into such common use that all thought of their origin has disappeared, such as paris green, bordeaux mixture, etc., should be written with lower case letters.

Also, use a. m. and p. m.

ORTHOGRAPHY

The Standard Dictionary should be used as the authority for spelling, compound words, etc., except where in conflict with recognized usage in the case of scientific terminology as indicated by leading scientific journals.

The forms "sulfur," "sulfate," and "sulfuric" are used in the JOURNAL. In expressing percentage the % sign is used. The word "plot" rather than "plat" is preferred.

NUMERALS

All amounts of ten or less should be spelled out, *except* enumerations of weight, measure, distance, clock time, money, percentage, degrees, proportion, and age, when figures should be used. For example, use six plots, not 6 plots; but write 6 pounds, not six pounds.

Figures should also be used in groups of enumerations where any one enumeration is in excess of ten. Also, treat alike all numbers in connected groups. For example, write 3, 7, and 12 varieties, not three, seven, and 12 varieties.

To avoid confusion where two numbers occur together, as "11 2-ounce tubers," write "eleven 2-ounce tubers."

Figures beginning a sentence should be spelled out, also both numbers of two related amounts at the beginning of a sentence, thus, "Ten to twelve kernels were selected."

Numbers of 1,000 or more should be written with the comma, except of course in the case of year numbers.

Use figures for decimal fractions and supply a cipher when there is no unit, as 0.25. Avoid a mixture of common and decimal fractions.

Dimensions should be expressed as "8 by 12 inches," not "8 x 12 inches." Also in expressing range use "10 to 20 inches," not "10–20 inches."

Where dates occur in the text the name of the month should be written out in full and the day without termination, as "January 15," not "Jan. 15th." In tables the name of the month should be abbreviated, thus "Jan. 15." Do not use the expression "1/15."

ABBREVIATIONS

Units of measure, such as grams, pounds, bushels, inches, gallons, etc., should be written in full in the text, but should be abbreviated when used in a table.

However, when necessary, use cm for centimeter, cc for cubic centimeter, mm for millimeter, cmm for cubic millimeter, mg for milligram, kg for kilogram, sp. gr. for specific gravity, p. p. m. for parts per

million, F for Fahrenheit, and C for Centigrade, both in the text and in tables.

In expressing hydrogen-ion concentrations use the form pH.

READING PROOF

Galley proofs of all articles published in the JOURNAL are sent to the authors, together with the manuscript, in ample time for a careful reading of the article in type before publication. Prompt attention to the reading of the proof and its return at the author's earliest convenience will be appreciated by the Editor, as the JOURNAL should not go to press until all proof has been returned.

In all cases the manuscript should be returned with the corrected proof.

Corrections on the galley proofs should be limited to only the most essential changes. The Editor exercises every care in the correction of typographical errors, but cannot assume responsibility for errors in statement of fact or in tabular matter that may have crept into the manuscript. Therefore, a careful reading by the author back to the original copy is highly desirable.

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A NOMINATING Committee was appointed by Dr. S. C. Salmon, Chairman of the Crops Section, and included O. S. Aamodt, Chairman, and F. D. Keim and Ide P. Trotter. At the business meeting of the Section held in Chicago, Ill., December 6, 1940, this Committee presented the following slate of officers for the Section for 1941 which was unanimously approved: For Chairman of the Section, C. J. Willard, Ohio State University, and as members of the Executive Committee of the Section, Glenn W. Burton of the U. S. Dept. of Agriculture and Karl S. Quisenberry of the University of Nebraska.

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NEWS ITEMS

DOCTOR MATTHEW DROSDOFF, formerly of the Division of Soil Survey, Bureau of Plant Industry, U. S. Dept. of Agriculture, has been transferred to the Field Laboratory for tung investigations at Gainesville, Fla. Dr. Walter Reuther, who received the Ph.D. degree at Cornell University in June 1940, was recently appointed Agent of the U. S. Dept. of Agriculture in the tung investigations and assigned to duty at the Field Laboratory at Gainesville.

ON NOVEMBER 11, Professor T. B. Hutcheson of the Virginia Agricultural Experiment Station, while on an elk hunt, suffered the misfortune of being pinned under a falling tree which resulted in fractured pelvic bones. He was taken to St. Elizabeth's Hospital at Pearisburg, Virginia, where he will likely remain until about Christmas.

A. M. BAISDEN, a graduate of Alabama Polytechnic Institute, who has been employed by the Virginia Agricultural Experiment Station as Junior Soil Surveyor since April 1938, was assigned the duties as Superintendent of the new branch experiment station being established in Orange County, Virginia, on December 12.

P. C. CONNER, who has been employed by the Virginia Agricultural Experiment Station as Junior Soil Surveyor since August 1938, has just accepted the position of Assistant Extension Forester for the Virginia Agricultural Extension Service, effective January 1, 1941. Mr. Conner is a native of Patrick County, Virginia, and a forestry graduate of North Carolina State College.

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